"EFFECT OF ATTACHMENT TYPE ON TORQUING OF MAXILLARY INCISORS IN ALIGNER ORTHODONTICS: A FINITE ELEMENT STUDY"

Dissertation submitted to

SANTOSH DEEMED TO BE UNIVERSITY, GHAZIABAD, NCR DELHI

In partial fulfillment of the requirement for the degree of

MASTER OF DENTAL SURGERY

In the Speciality of

ORTHODONTICS & DENTOFACIAL ORTHOPEDICS

Deemed to be University

(Established u/s 3 of the UGC Act, 1956)

By

Dr. NALIN YADAV

Under the guidance of

(Prof) Dr. NISHANT GUPTA

Professor

DEPARTMENT OF ORTHODONTICS & DENTOFACIAL ORTHOPEDICS

SANTOSH DENTAL COLLEGE & HOSPITALS

GHAZIABAD- 201009, NCR DELHI, INDIA

Batch 2022-23

Deemed to be University

(Established u/s 3 of the UGC Act, 1956)

COPYRIGHT

DECLARATION BY THE CANDIDATE

I, **Dr. NALIN YADAV** hereby, declare that the **Santosh Deemed to be University, Ghaziabad, NCR Delhi** shall have the right to preserve, use and disseminate this dissertation in print or electronic format for academic or research purpose.

Date: **Dr. NALIN YADAV**

Place:

Deemed to be University

(Established u/s 3 of the UGC Act, 1956)

DECLARATION BY THE CANDIDATE

I, **Dr. NALIN YADAV**, hereby declare that this dissertation entitled **"EFFECT OF ATTACHMENT TYPE ON TORQUING OF MAXILLARY INCISORS IN ALIGNER ORTHODONTICS: A FINITE ELEMENT STUDY"** is a bonafide genuine research carried out by me under the esteemed able guidance of my guide **Dr. NISHANT GUPTA (MDS),** Professor, Department of Orthodontics & Dentofacial Orthopedics, Santosh Dental College & Hospitals, Ghaziabad, NCR Delhi & co-guide **Dr. MAYANK GUPTA (MDS),** Reader, Department of Orthodontics & Dentofacial Orthopedics, Santosh Dental College & Hospitals, Ghaziabad, NCR Delhi.

Date: **Dr. NALIN YADAV**

Deemed to be University

(Established u/s 3 of the UGC Act, 1956)

ENDORSEMENT BY PRINCIPAL OF THE INSTITUTION

This is to certify that the dissertation entitled **"EFFECT OF ATTACHMENT TYPE ON TORQUING OF MAXILLARY INCISORS IN ALIGNER ORTHODONTICS: A FINITE ELEMENT STUDY."** is a bonafide research work done by **Dr. NALIN YADAV** himself under the esteemed guidance of **Dr. NISHANT GUPTA (MDS)** Professor, Department of Orthodontics & Dentofacial Orthopedics, Santosh Dental College and Hospitals, Ghaziabad, NCR Delhi.

Date:

Place:

(Prof) Dr. AKSHAY BHARGAVA

DEAN
MDS (Prosthodontics)
AFAAID, DICOI, DWCOI
Santosh Dental College and Hospitals
Ghaziabad, NCR Delhi

Deemed to be University

(Established u/s 3 of the UGC Act, 1956)

CERTIFICATE BY THE GUIDE

This is to certify that the dissertation entitled **"EFFECT OF ATTACHMENT TYPE ON TORQUING OF MAXILLARY INCISORS IN ALIGNER ORTHODONTICS: A FINITE ELEMENT STUDY."** is a bonafide, genuine research work carried out by **Dr. NALIN YADAV** in partial fulfillment of the requirement for the degree of Master of Dental Surgery in the specialty of Orthodontics & Dentofacial Orthopedics.

GUIDE:

Dr. NISHANT GUPTA
Professor
Department of Orthodontics & Dentofacial Orthopedics
Santosh Dental College & Hospitals
Ghaziabad, NCR Delhi.

CO-GUIDE:

Dr. MAYANK GUPTA
Reader
Department of Orthodontics & Dentofacial Orthopedics
Santosh Dental College & Hospitals
Ghaziabad, NCR Delhi.

Deemed to be University

(Established u/s 3 of the UGC Act, 1956)

CERTIFICATE BY HEAD OF THE DEPARTMENT

This is to certify that the dissertation entitled **"EFFECT OF ATTACHMENT TYPE ON TORQUING OF MAXILLARY INCISORS IN ALIGNER ORTHODONTICS: A FINITE ELEMENT STUDY."** being submitted by **Dr. NALIN YADAV** in partial fulfillment of the regulations for the award of the degree of Master of Dental Surgery in the specialty of Orthodontics & Dentofacial Orthopedics, is based on the bonafide work carried out by him under my direct guidance and supervision, and completed to my full satisfaction.

Dr. RAJIV AHLUWALIA

Professor & Head
Department of Orthodontics & Dentofacial Orthopedics
Santosh Dental College & Hospitals
Ghaziabad, NCR Delhi

Deemed to be University

(Established u/s 3 of the UGC Act, 1956)

ANTI- PLAGIARISM DECLARATION/UNDER TAKING

I, **Dr. NALIN YADAV**, hereby declare that the present dissertation entitled **"EFFECT OF ATTACHMENT TYPE ON TORQUING OF MAXILLARY INCISORS IN ALIGNER ORTHODONTICS: A FINITE ELEMENT STUDY."** submitted by me to Santosh Deemed to be University is a bonafide original research work. I also hereby declare that there is no plagiarism and the present research work has not been submitted for the award of any degree/diploma of the same institution where the work was carried out or to any other institution.

Dr. Nalin Yadav

I have verified the contents of the thesis, and the similarity index is 5%

Date:

Dr. JYOTI BATRA

DEAN RESEARCH

Place: Santosh Deemed To Be University

Dedicated to My Respected Teachers, Beloved Parents, Wife, Son and Brothers & My Friends

ACKNOWLEDGEMENTS

I bow down and express my deepest gratitude to Lord Krishna, whose guidance and blessings have been a source of strength and inspiration throughout my research journey. His teachings have guided my research and provided me with the strength and perseverance to overcome challenges and the wisdom to seek knowledge. Thank you for your divine presence in my life.

I express my deepest gratitude to my most respected teacher and my guide, ***Dr. Nishant Gupta,*** *Professor, Department of Orthodontics and Dentofacial Orthopedics, Santosh Dental College and Hospitals, Ghaziabad, for his keen interest, precious and invaluable guidance during my course. His excellent clinical skills, profound knowledge, and experience in the field of Orthodontics and Dentofacial Orthopedics will go a long way in framing my future career. I remain most indebted to him for his invaluable suggestions, his painstaking supervision, help, and encouragement for my thesis. No amount of thanks and gratitude can equal all that he has done for me.*

I extend my gratitude and thanks to my respected co-guide, ***Dr. Mayank Gupta,*** *Reader, Department of Orthodontics and Dentofacial Orthopedics, Santosh Dental College and Hospitals, Ghaziabad, for his constant encouragement and suggestions at every step in the formulation of this thesis, without which this work would have remained a difficult job to accomplish. His positive attitude and guidance with a smile always encouraged me to work harder each time.*

I wish to express my sincerest regards to ***Dr. Akshay Bhargava****, Dean, Professor, Department of Prosthodontics & Crown and Bridge, Santosh Dental College & Hospitals, Ghaziabad, and other Respectable Members of Ethical Committee for permitting and providing mean opportunity to do thesis work in the Institution.*

My special thanks to ***Dr. Rajiv Ahluwalia,*** *Professor and Head****.*** *Department of Orthodontics & Dentofacial Orthopedics, Santosh Dental College and Hospitals, Ghaziabad, for his helpful suggestions and guidance during my post-graduation period. He has taught me the most valuable skills to master my course. I am and will be forever*

grateful to him for his guidance. His encouraging attitude has always motivated me to love this subject and my work.

I wish to express my deepest regards to ***Dr. Tina Chugh****, Reader, Department of Orthodontics & Dentofacial Orthopedics, Santosh Dental College and Hospitals, Ghaziabad, for her help and cooperation. I am extremely grateful for her untiring help, invaluable guidance, and affectionate attitude.*

A sincere word of thanks to my seniors, ***Dr. Hemlata Bajaj, Dr. Anamika Sharma, Dr. Palak Kulshreshtha, Dr. Shivangi Shukla, Dr. Shikha Upadhyay,Dr. Mohit Patil & Dr. Shreyash Gupta*** *who taught me as a friend and as a guide. I will always remember and cherish their guidance and friendship.*

I am extremely grateful to my colleagues ***Dr. Komal Garje, Dr. Puja Kumari, Dr. Amrit Singh, & Dr. Shambhavi Rajput*** *for making PG-life playful and for all their help in the times of need. They have not only been excellent peers but also dear friends who have challenged and guided me all along the way, helping me grow both academically and personally. Cheers to my juniors* ***Dr. Aditi Jain, Dr. Priyanka Thomas, Dr. Harshita Dabas, Dr. Priyanka Roy Ballav, Dr. Adithya Nair, Dr. Samreen, Dr. Anjana, Dr. Kankalina & Dr. Abhishek*** *who were always there to support me and help in times of need. I would like to thank all seniors and juniors individually for making my days filled with fun, laughter, and mirth.*

I would also like to extend my gratitude to my fellow postgraduates from other departments, ***Dr. Mahitosh, Dr. Pratibh, Dr. Rajiv Singh, Dr. Rushi Kaknale, Dr. Ambika, & Dr. Manisha*** *who have been such a big support to my post-graduation year.*

I am thankful to ***Madhuri ji, Rajneesh Pathak & Pradeep Kumar*** *our lab technician, for their timely help and support in my laboratory work.*

Lastly and most importantly, I would like to express my heartfelt gratitude to my family for their incredible support, encouragement, and love during my dissertation journey. I am deeply grateful to my parents, ***Er. Nalini Kant Yadav & Mrs. Malti Yadav*** *who have been my rock throughout this journey. Their love and understanding have given me the strength to overcome any obstacle. I am also grateful to my loving wife,* ***Er. Shikkha Yadav & my***

son Mst Adhrit *for their love, support, and teasing me every time, so I was relieved from tiredness. and my father-in-law,* ***Advocate Nem Singh Yadav*** *who always showers his love and blessings, and my uncle and auntie****, Mrs Anupam Sharma & Mr Rajkumar*** *without their love and support, I would not have been able to get here. I would also like to thank my friends,* ***Dr. Vipul Garg, Dr. Sanjay Maurya, Dr. Jaibeer Rathi, Dr.Prachi Goyal, Dr. Kamil Ansari, Dr. Amir, Dr. Avinash, Dr. [PhD] Debabrata Acharya & Mr Giriraj Rawat*** *helped me anytime whenever I was in need and motivated me from every aspect.*

*Last but not least****, Brother Advocate Saroj Yadav, Advocate Rahul Yadav, & Mr. Manish*** *for their love, support, and encouragement, were behind me whenever I was in need, and have been invaluable to me. I am forever grateful for your unwavering faith in me and for being my pillar of strength during my post-graduation.*

I also thank all those who have contributed directly or indirectly to the completion of my thesis.

CONTENTS

S.No.	TITLE	Page No.
1	INTRODUCTION	1-5
2	AIM & OBJECTIVES	6-7
3	REVIEW OF LITERATURE	8-26
4	MATERIALS & METHOD	27-38
5	RESULTS	39-67
6	DISCUSSION	68-76
7	CONCLUSION	77
8	SUMMARY	78-79
9	BIBLIOGRAPHY	80-85
10	ANNEXURES	86-88

LIST OF TABLES

Table No.	TITLE	Page No.
1.	Material properties assigned	32
2.	Summary of FE Model Details	32
3.	Von Mises Stress and Tooth Displacement	40
4.	Displacement at the crown of teeth and the root of teeth, load applied is 100gm and 50 gm.	43

LIST OF FIGURES

Figure No.	FIGURES	Page No.
1.	Spiral C.T. scanning machine.	33
2.	CT scan Images and Steps.	34
3.	Creation of surfaces using STL format from Mimics and Hypermesh Software.	35
4.	Geometric model of the Central incisor.	35
5.	Exploded view of the without Composite attachment.	36
6.	Exploded view of model with aligner and ellipsoidal composite attachment	36
7.	Exploded view of model with aligner and semi-ellipsoid composite attachment	37
8.	Exploded view of model with aligner and rectangular power ridge	37
9.	Exploded view of model with aligner and power ridge on both sides	38
10.	Displacement contour in Maxillary Central Incisor with only Thermoplastic Aligner with 100 gm load –no attachment	47

11.	Stress contours of Thermoplastic Aligner on maxillary central incisors with 100 gm load in tooth –no attachment	47
12.	Stress contours of Thermoplastic Aligner on maxillary incisors PDL area with 100gm load in tooth –No attachment.	48
13.	Displacement and Stress contours in the sectional view of the aligner on the maxillary incisors area with maximum Von-Mises stress without attachment, Aligner with 100gm load in tooth –No attachment.	48
14.	Displacement contour of Thermoplastic Aligner in Maxillary Central Incisor with Horizontal Ellipsoid Attachment at 100gm load.	49
15.	Displacement contour of thermoplastic aligner in maxillary central incisor with Horizontal Ellipsoid Attachment with 100 gm load.	50
16.	Stress contours of thermoplastic aligner on maxillary central incisors with Horizontal Ellipsoid attachment with 100 gm load in the tooth	51
17.	Displacement contour of thermoplastic aligner in maxillary central incisor with Horizontal Ellipsoid Attachment with 100 gm load	52
18.	Displacement contour of thermoplastic aligner in maxillary central incisor with Horizontal Ellipsoid Attachment with 100 gm load	52

19.	Stress contours of Thermoplastic aligner at PDL on maxillary central incisors with Horizontal Ellipsoid attachment with 100 gm load in tooth.	53
20.	Displacement and Stress contours of the Thermoplastic Aligner in sectional view with Horizontal Ellipsoid attachment, with the aligner on the maxillary incisors area with 100 gm load in the tooth.	53
21.	Displacement contour of Thermoplastic Aligner in Maxillary Central Incisor with only Semiellipsoidal Attachment at 100 gm load	54
22.	Displacement contour of thermoplastic aligner in maxillary central incisor with Semiellipsoidal Attachment with 100 gm load.	55
23.	Stress contours of thermoplastic aligner on maxillary central incisors with Semiellipsoidal attachment with 100 gm load in tooth.	56
24.	Stress contours of the Thermoplastic aligner at PDL on maxillary central incisors with Semiellipsoidal attachment with 100 gm load in the tooth.	56
25.	Displacement and Stress contours of the Thermoplastic Aligner with Semiellipsoidal attachment, with 100 gm load in the tooth.	57
26.	Displacement contour of Thermoplastic Aligner in Maxillary	58

	Central Incisor with only Rectangular Power ridge at 100 gm load.	
27.	Displacement contour of Thermoplastic Aligner in maxillary central incisor with Rectangular Power ridge Aligner with 100 gm load	59
28.	Stress contours of thermoplastic aligner on maxillary incisors with Rectangular Power ridge with 100 gm load in tooth	60
29.	Stress contours of Thermoplastic aligner at PDL on maxillary central incisors with Rectangular Power ridge with 100 gm load in tooth.	60
30.	Displacement and Stress contours of the Thermoplastic Aligner in a sectional view with a rectangular power ridge attachment, with 100 gm load in the tooth.	61
31.	Displacement contour of Thermoplastic Aligner with Rectangular Power ridge on both Labial and Lingual side in Maxillary Central Incisor with at 100 gm load.	61
32.	Displacement contour of thermoplastic aligner in maxillary central incisor with Rectangular Power ridge with 100 gm load	62
33.	Stress contours of thermoplastic aligner on maxillary central incisors with rectangular power ridge attachment with 100 gm load in tooth	62
34.	Stress contours of Thermoplastic aligner at PDL on	63

	maxillary central incisors with rectangular power ridge attachment with 100 gm load in tooth	
35.	Displacement and Stress contours of the Thermoplastic Aligner in sectional view with rectangular power ridge attachment on both sides of max. incisors with 100 gm load.	63
36.	Displacement contour in Maxillary Central Incisor with only Thermoplastic Aligner with 50 gm load –no attachment.	64
37.	Displacement contour of maxillary central incisor with only Thermoplastic Aligner with 50 gm load –no attachment.	64
38.	Displacement contour in Maxillary Central Incisor with thermoplastic Aligner with 50 gm load – Dual power ridge.	65
39.	Displacement contour in Maxillary Central Incisor with thermoplastic Aligner with 50 gm load – Dual power ridge	65
40.	Stress contours of the Thermoplastic aligner at PDL on maxillary central incisors with 50 gm load in the tooth- Dual power ridge	66

LIST OF GRAPH

Graph No.	TITLE	Page No.
1	Displacement Comparison at Crown and Root under 100 gm and 50 gm load	44
2	Stress comparison graph on Teeth and PDL.	44

LIST OF ANNEXURES

S. No.	TITLE	Page No.
1	Ethical Clearance Certificate	86
2	Lab Certificate	87
3	Anti-Plagiarism Check Report	88

LIST OF ABBREVIATIONS

S. No.	ABBREVIATION	Full Form
1	3D	3- Dimensional
2	CT	Computed Tomography
3	CATIA	Computer-Aided Three-dimensional Interactive Application
4	CAD	Computer-Aided Device
5	CAM	Computer-Aided Manufacturing
6	DIACOM	Digital Imaging and Communication in Medicine
7	FEM	Finite Element Method
8	gm	gram
9	MIMICS	Materialise Interactive Medical Image Control System
10	MPa	Mega-Pascal
11	OS	Operating system
12	PDL	Periodontal ligament
13	RAM	Random Access Memory
14	STL	Stereolithography

Introduction

INTRODUCTION

The evolution of orthodontic appliances has evolved through time with various appliance systems, including the edgewise appliance, preadjusted edgewise appliance, Tip-Edge system, and Begg's light-wire differential force technique. There has been a growing demand for esthetically favorable treatment modalities, leading to the development of less visible or invisible systems such as thermoplastic aligners and lingual orthodontics.[1] Despite initial enthusiasm, both aligner systems and lingual appliances experienced a subsequent period of limited adoption, largely due to inherent biomechanical limitations and clinical challenges. At present, the orthodontic treatment is undergoing a phase characterized by intensive learning, research, and innovation aimed at optimizing the efficacy of these aesthetic treatment modalities. Given the critical importance of anterior torque control, particularly due to the difficulty of regaining control once it is lost, clinicians must ensure vigilant monitoring and precise management of torque from the outset of treatment.[1] As torque control in aligner therapy involves complex biomechanics, a thorough understanding of the torquing mechanisms employed by thermoplastic aligners is essential

In fixed appliances, torque is typically generated by creating equal and opposite moments within the bracket-wire interface. In contrast, thermoplastic aligners achieve torque by incorporating force-inducing projections within the aligner or placing attachments on the tooth surface.[1] These custom-designed aligners are fabricated in specialized laboratories using detailed impressions or digital scans of the patient's teeth. Each successive aligner is engineered to apply precise forces that gradually move the teeth toward the desired final alignment.[2] The primary advantages of clear aligners include their discreet, metal-free appearance and the improved ability to maintain oral hygiene, thanks to their removability.

However, this method also has limitations, such as the inability to perform chairside adjustments and higher laboratory costs. Unlike conventional braces, which use brackets and wires to exert controlled pressure on teeth, clear aligners rely on customized plastic trays to gently guide tooth movement. Achieving consistent aligners torquing is a challenging process in the maxillary anterior region, where precise root control is critical Previous studies have highlighted that clear aligner therapy has notable limitations, particularly in achieving torquing and extrusive tooth movements.[3] Effective torque management is crucial for achieving optimal occlusion, enhancing facial aesthetics, and ensuring the long-term stability of orthodontic treatment outcomes. Inadequate torque control may result in improper overjet, anterior open bites, and an increased risk of post-treatment relapse.[4] Torque control is a biomechanically demanding orthodontic movement that often necessitates overcorrection to achieve the desired results. Attachments play a vital role in improving the efficiency of clear aligner therapy, particularly for complex movements such as torquing of the maxillary incisors.

Torquing involves the controlled movement of the root in the buccal or lingual direction while keeping the incisal edge stationary. During bodily tooth movement, especially during the retraction phase, teeth tend to tip in the palatal/lingual direction, compromising treatment goals. This undesired tipping can be minimized through the use of horizontal rectangular beveled attachments, which enhance the aligner's grip and facilitate more effective torque expression.[5] Clear aligners depend on attachments to improve force application and increase the predictability of such movements, unlike conventional braces, where arch wire interactions with the bracket slot produce torque. Attachments are composite resin constructions placed onto the tooth surface to provide more grip, hence producing mechanical interlocking between the aligner and the tooth. In circumstances needing greater torque, the lack of attachments might cause uncontrolled tipping instead of appropriate root movement.[2] A good torque movement depends on appropriate attachment

design and positioning, as aligners have biomechanical restrictions.

Torquing movement without attachment relies mainly on the force and thickness of the aligner material, however, the torquing is less predictable and takes a longer duration in such scenarios.[2] Rectangular, ellipsoid, and optimized attachments are the most often employed for torque control among many forms of attachments designed to enhance force transfer in aligner treatment. Flat surfaces of attachments help to maximize aligner contact and force application, thus rectangular attachments are often used for incisor torquing. They also reduce undesired tipping along with the aligner retention.[6] Recent developments in digital orthodontics have brought optimized attachments that are specially created utilizing artificial intelligence and computer algorithms based on patient-specific treatment plans.[6]

Some studies are exploring the different type of attachments design on clear aligner therapy, particularly during the movement of the maxillary central incisor, has been extensively explored through finite element method (FEM) analysis. Studies comparing various attachment configurationssuch as horizontal rectangular, ellipsoid, and beveled rectangularhave demonstrated that the horizontal rectangular design produces the highest level of extrusive movement, whereas the ellipsoid and beveled rectangular attachments generate progressively lesser extrusion forces. Notably, across all configurations, a consistent pattern of palatal tipping has been observed during extrusion. Expanding on these findings, Costa *et al*[7] investigated the effects of custom-designed composite attachments, which were modifications of standard attachment forms. Their analysis included a broader range of designs, namely ellipsoid, rectangular, beveled rectangular, pyramidal, quarter, and vertical ellipsoid. The study concluded that attachment geometry plays a critical role in influencing both the magnitude and direction of forces delivered by aligners.[7]

Orthodontic biomechanics research has historically been constrained by ethical limitations

associated with invasive studies on human tissues. While clinical trials offer valuable data, they often face challenges such as biological variability, extended durations, and ethical restrictions. In this context, the Finite Element Method (FEM) has emerged as a powerful, non-invasive tool for simulating orthodontic forces and analyzing their effects on dental and periodontal structures. Compared to traditional models like photoelastic analysis, FEM allows three-dimensional, detailed assessment of internal structures, including the periodontal ligament (PDL) and alveolar bone, under controlled and reproducible conditions.

FEM has been extensively applied to investigate various orthodontic mechanics, including torque, intrusion, extrusion, and rotation. Prior studies have demonstrated its utility, McGuinness et al[8]utilized the FEM to evaluate how orthodontic forces are distributed when applied through the edgewise appliance. Studies by Knop et al,[9] Kojima&Fukui,[10] Tominaga et al,[11]Kanjanaouthaia et al[12]have shown the FEM can be important tool inorthodontics to understand & comprehend various tooth movement, stress distribution, effect of appliance on tooth, PDL & bone.

High-fidelity FEM analysis depends on accurate anatomical modeling, typically reconstructed from high-resolution CT data using software such as MIMICS or Simpleware. Although clinical CT imaging presents limitations in segmenting delicate structures like the PDL due to poor contrast, FEM remains an indispensable tool for evaluating aligner biomechanics.[9] It enables the visualization of stress patterns and force vectors, identifies high-risk zones for tissue damage, and supports the preemptive optimization of treatment strategies. Moreover, FEM facilitates comparisons between standard and customized attachments, offering insights into how design modifications can improve torque efficiency by optimizing force direction and magnitude.[9,12,13]

Despite advancements in clear aligner therapy, achieving precise torque control of

maxillary central incisors remains a clinical challenge, primarily due to the material limitations of aligners and their dependence on plastic deformation rather than direct force application. Inadequate torque control may lead to compromised occlusion, aesthetic deficits, relapse, and periodontal complications.[13] While FEM has significantly advanced the understanding of these mechanics, comparative studies assessing different attachment designs remain limited. Most existing literature has evaluated isolated attachment types, with insufficient data directly comparing aligners without attachments, labial rectangular power ridge attachments, horizontal ellipsoidal attachments, semicircular attachments, and dual labial-palatal power ridge configurations.

To address this gap, the present study utilizes FEM to systematically compare the biomechanical efficiency of these attachment designs in controlling maxillary central incisor torque.According to Profitt,[14]the force required to bring aboutthe torquingis in the range of 50-100 gm,therefore, in this study, we have assessed the impact of two force magnitudes (50 gm and 100 gm) to determine the attachment configuration that delivers the most controlled and effective torque expression. This study aims to enhance evidence-based aligner treatment planning by providing biomechanical insights while adhering to ethical standards through advanced digital simulation techniques.

***

Aim & Objectives

AIM AND OBJECTIVES

AIM

To study the effect of different attachment designs on the torquing movement of the maxillary incisor with aligners using finite element method.

OBJECTIVES

1) To evaluate the effectiveness of only an aligner without attachment for the torquing of incisors.
2) To check the effectiveness of horizontal ellipsoid attachment to achieve torquing in the incisor teeth.
3) To check the effectiveness of semi-ellipsoid attachment to achieve torquing in the incisor teeth.
4) To check the effectiveness of the rectangular power ridge on the labial aspect to achieve torquing in incisor teeth.
5) To check the effectiveness of the rectangular power ridge on labial as well as palatal aspects. to achieve torque in the incisor teeth.

RESEARCHHYPOTHESIS

NULL HYPOTHESIS:

Attachment shape does not affect the Torquing of maxillary incisors in aligner therapy.

ALTERNATIVE HYPOTHESIS:

Attachment shape affects the extent of the Torquing movement of maxillary incisors in aligner therapy.

***

Review of Literature

REVIEW OF LITERATURE

McGuinness *et al* (1992)[8] used finite element analysis to evaluate how edgewise orthodontic appliances affect stress distribution in the periodontal ligament (PDL). Their model simulated a maxillary central incisor subjected to different orthodontic forces. Results showed that stress concentrations varied with force direction, especially near the apex and cervical areas. This study emphasized the importance of controlled force application to minimize risks like root resorption. As one of the early FEM applications in orthodontics, it laid foundational groundwork for understanding the biomechanical behavior of teeth under orthodontic loading.

Melsen B *et al* (2007)[15] discussed the relevance of force levels in tooth movement. They highlighted that orthodontics and orthopedics have devoted considerable study to the reaction of the alveolar bone to orthodontic force levels, guided by the traditional pressure-tension hypothesis that links pressure zones with bone resorption and tension zones with apposition. However, orthopedic studies indicate that unloading produces a negative bone remodeling balance while loading increases bone density, thus emphasizing the importance of mechanical stimulation in bone homeostasis. Using monkey models, histological studies have provided significant new perspectives on the nature of alveolar bone resorption under various stress levels. Lower force levels have been associated with direct resorption, marked by osteoclast-mediated bone degradation at the compression point. Conversely, undermining resorption is a secondary healing mechanism wherein the alveolar bone underneath ischemic periodontal ligament (PDL) areas is resorbed due to osteocyte necrosis or death, as seen by empty osteocyte lacunae. The strain distribution across the alveolar bone, rather than simple pressure or tension zones, determines the remodeling response.

Jayade *et al* (2007)[5] reported that FEA had evolved into a crucial computational tool that replicated and evaluated the mechanical behaviour of orthodontic equipment and tooth motions under various stress conditions. Their work demonstrated that FEA's application in orthodontic research ensured the prediction of treatment outcomes and aided in maximizing appliance design, particularly in the context of torque control. Finite Element Analysis (FEA) to model and evaluate the biomechanical behaviour of teeth and orthodontic equipment under different loading conditions. Their study assessed the magnitudes of first and laterdeactivational thirdorder moments produced in rectangular twisted archwires. The findings indicated that the generated moments could be significant, potentially increasing the likelihood of root resorption. The study cautiously concluded that twists in rectangular archwires should be employed, notably in cases where reciprocal torque is required on neighbouring teeth.

Kravitz *et al* (2008)[16] investigated the factors influencing the accuracy of canine rotation with Invisalign, focusing on the roles of attachments and interproximal reduction (IPR). In their study, they analysed 53 maxillary canines in 30 patients, comparing predicted movements with actual clinical outcomes. The authors found that the overall accuracy of canine rotation using Invisalign was approximately 35%, with significantly better outcomes when optimized attachments were used. Additionally, they reported that rotations greater than 15 degrees were considerably less accurate, highlighting the biomechanical limitations of clear aligners for complex rotational movements. The incorporation of attachments and the use of IPR were shown to improve rotational control, albeit modestly. This study underscores the importance of auxiliary features in enhancing aligner efficacy, especially for challenging tooth movements such as canine rotation.

Kojima & Fukui (2008)[10] used finite element analysis to examine how a transpalatal arch (TPA) influences maxillary molar movement when mesial forces are applied. Their 3D simulation showed that adding a TPA helped control molar tipping and rotation, especially in the transverse dimension. The TPA provided added anchorage by promoting more controlled, bodily tooth movement instead of unwanted tipping. This study highlighted the biomechanical role of TPAs in anchorage management and demonstrated the value of finite element modelling in predicting tooth movement. It serves as a key reference for understanding how auxiliary appliances can optimize force systems in orthodontic treatment.

Tominaga *et al* (2009)[11] investigated how different force directions affect the controlled movement of maxillary anterior teeth during sliding mechanics using 3D finite element analysis. Their study evaluated the effect of altering the vertical position and angulation of retraction forces applied from an anterior hook to the posterior segment.They found that applying force closer to the teeth centre of resistance promoted bodily movement rather than tipping. This highlights the importance of not just the magnitude but also the direction and point of force application in achieving efficient and controlled tooth movement. The research emphasized the clinical value of adjusting retraction hook height and force vector to optimize anterior retraction outcomes while preserving anchorage. By combining biomechanical modelling with clinical relevance, this study contributed to refining force application strategies in sliding mechanics, influencing later work on torque control and retraction techniques.

Liang W *et al* (2009)[17] This study aimed to compare the biomechanical behaviour of maxillary incisors during retraction using labial and lingual orthodontic techniques through three-dimensional finite element analysis. A finite element model of the maxilla,

including maxillary incisors, was developed with 98,106 nodes, 71,944 elements, and 5,236 triangle shell units. Horizontal retraction force, vertical intrusive force, and lingual root torque were applied to simulate both labial and lingual orthodontic treatments. The distribution of stress and strain in the periodontal ligament (maximum and minimum principal stresses and strains), total displacement, and displacement vector of the maxillary central incisor were analysed. Results showed that under identical force magnitudes, labial orthodontics produced bodily translation of the incisor, whereas lingual orthodontics led to lingual crown tipping, indicating diminished torque control in lingual systems. It was concluded that lingual orthodontic treatment requires specific biomechanical adjustments namely, increasing lingual root torque and vertical intrusive force while reducing horizontal retraction force to achieve effective and controlled tooth movement.

Kanjanaouthai *et al* (2012)[12] explored how changes in the inclination of a maxillary central incisor affect stress within periodontal structures using finite element analysis (FEA). By modelling various tooth angulations (70°–120°) and applying occlusal forces, they assessed stress distribution in the periodontal ligament (PDL) and surrounding bone. Their analysis showed that extreme proclination or retroclination increases stress, especially near the root apex and cervical margin, while an upright position (~90°) results in more favourable load distribution. These findings highlight the biomechanical importance of proper axial inclination in minimizing periodontal strain. The study emphasizes the clinical significance of maintaining optimal incisor angulation during orthodontic treatment to reduce the risk of periodontal damage. It also demonstrates the value of FEA as a tool for visualizing internal stress responses not evident through clinical observation.

Musilli M *et al* (2012)[19] A anterior torque correction with bracketless fixed orthodontics.This technique utilizes a custom-designed lingual spring to apply controlled forces directly to the lingual surfaces of anterior teeth, allowing for targeted torque correction without the need for conventional labial brackets. The approach aligns with a growing trend in contemporary orthodontics to develop more discreet, patient-friendly alternatives that maintain clinical efficacy. The authors of the article highlight the biomechanical advantages of this system, including its ability to deliver precise torque forces while minimizing unwanted side effects. Furthermore, the use of lingual mechanics can be especially beneficial in adult orthodontics, where aesthetic concerns often preclude the use of visible labial appliances.

Krieger *et al* (2012)[20]Canine rotation with Invisalign presents a clinical challenge, with a reported mean accuracy of 35.8% (SD = 26.3). A comparative analysis revealed no significant difference in rotational accuracy among groups using attachments only, interproximal reduction (IPR) only, or neither (P = .343). Similarly, no difference was found between maxillary and mandibular canines (P = .888), indicating consistent limitations across arches.The vertical-ellipsoid attachment was the most frequently used (70.5%), yet did not significantly improve outcomes. These findings suggest that commonly used adjuncts like attachments and IPR have limited effectiveness in enhancing the rotational accuracy of canines with Invisalign, highlighting the need for improved biomechanical strategies in aligner therapy.

Castroflorio *et al* (2013)[21] evaluated the effectiveness of Invisalign® in controlling upper incisor root movement, focusing on torque expression. Using digital model superimposition and cephalometric analysis, they found that while aligners have inherent limitations in achieving controlled root movement due to their lack of fixed anchorage

and force application challenges, specific design features, such as optimized attachments and staging, can improve torque control. Though less effective than fixed appliances, the study demonstrated that with proper biomechanical planning, aligners can produce clinically acceptable root movements, highlighting the importance of attachment design and force direction in enhancing torque expression.

Simon *et al* (2014)[2] reported that attachments, which are composite resin constructions attached to teeth, increased mechanical interlocking between the aligner and the tooth surface, thereby enhancing the transfer of orthodontic forces. Their study using FEA examined how various attachment configurations affected maxillary incisor torque control and found that a semi-ellipsoid attachment produced more consistent stress distribution and improved control of labiolingual inclination compared to other designs.

Rossini G *et al* (2015)[3]Clear aligner therapy (CAT) has shown varying levels of effectiveness across different types of tooth movements. A review of eleven studiesincluding two randomized clinical trials, five prospective non-randomized, and four retrospective non-randomizedrevealed moderate risk of bias in six studies and unclear risk in the rest. CAT was effective in anterior intrusion, with a mean of 0.72 mm, but poorly controlled anterior extrusion (30% accuracy) and rotation, especially in rounded teeth. Upper molar distalization was the most predictable movement, with 88% accuracy for bodily movements of at least 1.5 mm. Arch alignment also improved, as reflected by a reduction in Little's Index (5 mm in the mandible, 4 mm in the maxilla). Additionally, CAT controlled posterior buccolingual inclination more effectively than anterior inclination. While CAT is reliable for intrusion, alignment, and certain posterior movements, its limitations in extrusion, anterior torque, and rotation warrant cautious interpretation of current findings due to the variability and quality of the available studies.

Dasy *et al* (2015)[22] found that ellipsoid attachments did not significantly improve retention in the aligners examined, whereas bevelled rectangular attachments were more effective in enhancing retention.

Rossini *et al* (2015)[23]Orthodontic treatments can impact periodontal health through both direct and indirect mechanisms. These effects are influenced by factors such as host immunity, systemic conditions, smoking, and oral hygiene practices. Fixed appliances, in particular, are linked to increased plaque accumulation and worsening periodontal parameters due to their complex structure, which hinders effective cleaning.

In contrast, removable appliances like clear aligners offer periodontal advantages by allowing easier maintenance of oral hygiene. With the rising demand for aesthetic and comfortable treatment options, especially among adults, clear aligner therapy (CAT) has become increasingly popular. CAT is generally considered safe and comfortable, with reduced impact on periodontal health when good hygiene is maintained.

Cai *et al* (2015)[24] investigated the optimization of attachment configurations in clear aligner therapy to enhance tooth translation by focusing on appropriate momenttoforce (M/F) ratios through biomechanical analysis. Using finite element models, they demonstrated that carefully designed attachments could generate optimal M/F ratios, promoting controlled bodily tooth movement rather than undesired tipping. Their study highlighted how variations in attachment shape and placement directly influence the force systems applied by aligners, ultimately improving treatment efficiency and predictability. This work laid important groundwork for integrating biomechanical principles into the design of transparent orthodontic appliances, emphasizing that precise control over force

and moment application is essential for advancing clear aligner efficacy and patient outcomes.

Lacarbonara *et al* (2015)[25]in their publication, Variable Torque Prescription: State of Art, explore the development and application of torque variability in orthodontic treatment. They underscore the role of precise torque control in achieving proper tooth alignment, particularly in the anterior segment, where aesthetics and occlusal function are critical The paper explains the rationale behind using different torque values tailored to each tooth's anatomical and functional requirements, moving beyond uniform bracket prescriptions.

Knop *et al* (2015)[8] reviewed the application of the Finite Element Method (FEM) in orthodontics, highlighting its role in simulating the mechanical behaviour of dental and periodontal structures under orthodontic forces. The study emphasized FEM's value in predicting stress and strain distribution, aiding in treatment planning and appliance design. While the method offers detailed, non-invasive biomechanical analysis, the authors note its accuracy depends heavily on precise input data and anatomical modelling. Despite inherent limitations, FEM is considered a powerful tool that continues to advance orthodontic research and practice.

Gomez JP *et al* (2015)[26] conducted a similar 3D finite element analysis to study the initial force system generated by upper canines moving with aligners with and without attachments. The study reaffirmed that composite attachments play a critical role in producing effective bodily movement, while their absence can lead to unfavourable tooth inclinations.

Garino *et al* (2016)[27] demonstrated that placing vertical rectangular attachments on five teeth resulted in increased distal movement of both the first molars and central incisors. Their findings indicated that these attachments played a crucial role in minimizing tipping during molar distalization while also improving anchorage in the posterior region.

Gao L & Wichelhaus A (2017)[28] investigated how gingival edge width and material thickness influenced the stresses and moments generated by aligners made from Duran foil (PET-G) on a maxillary incisor during tipping and intrusion. Aligners with varying material thicknesses (0.5, 0.625, 0.75 mm) and gingival edge widths (0–1, 3–4, 6–7 mm) were tested using a six-component measurement tool. The results showed that tooth movement direction, material thickness, and edge width significantly affected the forces and moments applied by the aligner.

Weir T (2017)[29] provides a comprehensive overview of clear aligners as a transformative modality in orthodontic treatment, highlighting their evolution from simple tooth positioning devices to sophisticated systems capable of managing complex tooth movements. The review emphasizes advancements in material technology and digital treatment planning, which have significantly improved the predictability and efficiency of aligner therapy. Additionally, Weir discusses the biomechanical principles underlying clear aligner function, including the importance of attachment design and staged tooth movements to optimize force application. The article also addresses clinical considerations such as patient compliance and treatment limitations, advocating for ongoing innovation to expand the scope of aligner use.

Yokoi Y & Arai A (2019)[30] investigated how attachment affects tooth movement generated by a plastic aligner. They used a finite element approach to simulate the closure

of a diastema, where the maxillary right and left central incisors migrated physically. They aggregated the first displacement of teeth generated by elastic deformation of the periodontal ligament to model long-term orthodontic motions of the maxillary dentition. They found that independent of the attachment, the incisor pointed and turned immediately after aligner insertion. Over a sufficiently long period, the incisor stayed pointed in the aligner without attachment, but it was straight and moved physically in the aligner with attachment, showing that the attachment was effective for obtaining physical mobility.

Gupta M *et al* (2020)[31] conducted a three-dimensional finite element analysis (3D FEM) to assess stress distribution on the periodontal ligament (PDL) and alveolar bone during various orthodontic tooth movements. The study simulated different types of movements, tipping, intrusion, extrusion, translation, and rotation to evaluate their biomechanical impact. Results revealed that each type of movement generated distinct stress patterns, with translation causing the highest stress on both the PDL and alveolar bone, followed by rotation and tipping. Intrusion and extrusion produced comparatively lower stress levels. These findings highlight the importance of understanding biomechanical responses during orthodontic treatment to minimize the risk of tissue damage and optimize force application. The study emphasizes that precise control of orthodontic forces is critical to ensuring safe and effective tooth movement.

Cattaneo PM *et al* (2021)[32] aimed to provide an updated overview of the application of finite element analysis (FEA) in understanding orthodontic tooth movement (OTM), with particular focus on model complexity, material properties, and anatomical representation. The objective was to evaluate how accurately FEA simulates biological responses during OTM, particularly emphasizing the role of the periodontal ligament (PDL). This review-

based study included a critical evaluation of previously published FEA models incorporating varying levels of anatomical detail (geometrical, anatomically simplified, and anatomically correct models) and material behaviour (linear, hyperelastic, viscoelastic, and anisotropic). Results indicated that simplified models may suffice for general estimations like centre of resistance, but biologically accurate models including detailed PDL geometry and complex material properties, are essential for precise strain and stress distribution predictions, root resorption risk assessments, and long-term OTM simulations. The study concluded that while FEA is a powerful tool in orthodontics, meaningful simulations depend on a balance between biological realism and computational feasibility, and emphasized the need for further validation of these models through experimental and in vivo data.

Gaddam *et al* (2021)[33] evaluated the reliability of torque expression in Invisalign® treatment by comparing predicted and achieved outcomes in 40 adult patients. The study found significant underexpression of labial crown torque, with mean discrepancies of 6.43° in upper central incisors and 5.06° in lateral incisors. In contrast, lingual or palatal torque movements were more accurately achieved or slightly overexpressed. Similar trends were observed in interincisal angle measurements. The findings suggest that Invisalign® may be less effective in achieving labial torque, indicating the need for overcorrection or auxiliary strategies in treatment planning.

V. Sandhya *et al* (2021)[1] Clear aligner therapy presents a favourable alternative to fixed appliances due to its aesthetic appeal and removability. However, achieving effective torque control, particularly of the maxillary incisors, remains a biomechanical limitation. Torque, defined as controlled root movement in the buccolingual direction, requires a precise moment-to-force ratio that standard thermoplastic aligners alone often fail to

generate.To enhance force delivery, auxiliary features such as composite attachments and power ridges have been incorporated. Horizontal ellipsoid composite attachments increase the aligner's contact surface, improving force transmission and control. Power ridges are preformed indentations in the aligner intended to deliver torque moments without bonded auxiliariesFinite element method (FEM) analysis is a validated computational approach for assessing the biomechanical performance of orthodontic appliances. It allows for detailed evaluation of stress distribution, force vectors, and tooth displacement under defined load conditions.This study aimed to compare the torque efficacy of three maxillary central incisor aligner configurationswithout auxiliaries, with horizontal ellipsoid composite attachment, and with power ridgeusing three-dimensional FEM. A torque force of 100 grams was applied to the upper right central incisor, and the resulting root movement, total displacement, and stress distribution were analysed to determine the most biomechanically effective design.

Costa R *et al* (2021)[7] investigated the impact of three different attachment types on the extrusive pressures in the maxillary central incisor from thermoplastic aligners. They evaluated three maxillary model prototypes with varying central incisor attachments. Force measurements along three axes were collected and analysed using ANOVA and Tukey's test ($\alpha = 0.05$). The study concluded that all three attachment types could produce satisfactory extrusion movements, though with varying force intensities. Among them, attachment 3 exhibited the best performance on the Z-axis (extrusion) but had limitations in force directionality along the X and Y axis, warranting further refinement and biological impact assessment.

Nucera R *et al* (2022)[34] examined the influence of attachment design on torque control in clear aligner therapy. Their findings highlight that the effectiveness of composite

attachments is largely dependent on their design and location. Properly placed attachments are critical for delivering the necessary force systems to achieve targeted orthodontic tooth movements. Finite Element Method (FEM) is pivotal during orthodontic tooth movement, allowing researchers and clinicians to forecast and visualize stress and strain within the periodontal ligament (PDL) and alveolar bone. This predictive capability enhances treatment effectiveness by aiding in the understanding of biomechanical responses to various orthodontic forces. FEM plays a critical role in assessing and improving the biomechanical performance of orthodontic equipment such as brackets and archwires through analysis of stress distribution and deformation patterns.Beyond conventional orthodontic use, FEM contributes significantly to craniofacial development studies and orthognathic surgery planning. By simulating orthopedic pressure responses and replicating surgical effects, FEM supports more informed, optimized treatment planning for jaw posture corrections and facial morphology adjustments. Cases involving tooth extractions have also been examined using FEM to evaluate torque mechanics of the upper anterior teeth with clear aligners.

Cheng *et al* (2022)[35] conducted a finite element analysis to evaluate the torque control of upper anterior teeth using clear aligners in extraction cases. Their study revealed that achieving effective lingual root torque with aligners is biomechanically challenging due to limited control over force direction and tipping tendencies. The simulations showed inadequate root displacement and increased crown tipping, highlighting the mechanical limitations of aligners when used without auxiliary aids. The findings underscore the need for optimized attachment designs or additional torqueing features to improve treatment outcomes, especially in complex extraction scenarios.

Bichu *et al* (2022)[36] highlighted how innovations in computer-aided design (CAD), computer-aided manufacturing (CAM), and material science are essential to the future of aligner performance. Their study reviewed current materials used in clear aligner fabrication, examined the role of shape memory polymers and 3D-printed aligners, and promoted sustainable manufacturing practices.They emphasized that without continuous innovation in aligner material chemistry and engineering, biomechanical limitations may continue to hinder treatment efficacy.

Ahmad *et al* (2023)[13] identified key factors affecting torque application efficiency, including archwire stiffness, the bracket-archwire interface, and the tooth's centre of resistance. Understanding these variables is vital for predicting and controlling tooth movement during treatment.

Jedliński M *et al* (2023)[37] conducted a systematic review to evaluate the effectiveness of composite attachments in aligner therapy, focusing on findings from finite element method (FEM) studies. The objective was to assess how attachment shape and positioning influence tooth movement efficiency and stress distribution. Eleven FEM studies were included, simulating movements such as incisor retraction, extrusion, rotation, molar intrusion, and distalization. The models tested various attachment designs (rectangular, ellipsoid, bevelled) and positions (labial, palatal, lingual, or dual). Results showed that attachments significantly improved force control, minimized unwanted tipping, and optimized periodontal stress. Palatal attachments enhanced incisor retraction, dual attachments improved molar intrusion, and vertical rectangular attachments were most effective for premolar rotation. Proper attachment configuration across multiple teeth provided better anchorage and movement precision. The review concluded that FEM

studies consistently support the strategic use of attachments to improve biomechanical efficiency and predictability in clear aligner orthodontics

Liu *et al* (2023)[38]conducted afinite element study which reveal that methods of micro-implant attachment, such as precision cuts or buttons, impact force distribution and movement patterns. Precision cuts generally offer superior control, enhancing the contribution of distal forces while slightly increasing molar tipping or rotation. Additionally, sequential distalization can cause reciprocal forces leading to relapse, particularly in second molars. Overall, integrating micro-implants optimizes anchorage and improves clinical outcomes during aligner-based distalization.

Castroflorio *et al* (2023)[39] examined the effect of treatment design on the predictability of orthodontic tooth movement with clear aligners. Their multicenter study used digital superimpositions to compare predicted versus achieved outcomes, revealing that certain movements, particularly torque, rotation, and extrusion, had lower accuracy. These discrepancies were not random but associated with specific treatment design factors such as staging, anchorage control, and the use of optimized attachments. The authors emphasized the need for personalized treatment planning and careful biomechanical consideration to improve aligner performance..

Vashishta A *et al* (2023)[6]in their review article explained the diverse types of attachments used in conjunction with clear aligner therapy (CAT), focusing on their designs, clinical effectiveness, and ideal positioning. Tailoring attachment selection to the specific malocclusion is essential for achieving precise, stable, and predictable treatment results. A thorough understanding and strategic application of these auxiliary elements can

significantly enhance the performance of clear aligners, aligning with the growing demand from adult patients for discreet, comfortable, and efficient orthodontic care.

Alhasyimi AA *et al* (2024)[40] aimed to investigate the effects of varying attachment designs and aligner thicknesses on the retraction of upper central incisors using clear aligners. They developed three models to replicate incisor retraction, each featuring a different attachment design rectangular, ellipsoid, and pyramidal with variable aligner thicknesses ranging from 0.75 mm to 1.15 mm. Using finite element analysis (FEA), they evaluated the stress distribution and mechanical reaction of the aligners on the upper central incisors. The study found that the optimal thickness for anterior retraction is between 0.75 and 0.85 mm, while a 0.95 mm thick aligner might be useful when a lot of power is needed. The ellipsoid attachment was the most effective due to its ability to generate and distribute force uniformly, enabling efficient movement.

Gandhi A *et al* (2024)[41] aimed to review the application of the finite element method (FEM) in orthodontics to explain its role in evaluating stress and deformation in biological structures during orthodontic tooth movement. The focus was on the methodological steps involved in FEM and how it enables non-invasive, precise, and quantitative analysis of physiological tissue responses, particularly at the interface between alveolar bone and periodontal ligament. FEM was utilized to predict tooth movement patterns under different orthodontic appliances by analysing stress distribution. The methodology required familiarity with specialized software to simulate orthodontic forces accurately. The results emphasized FEM's advantage over other experimental techniques by offering detailed visualizations and mechanical insights into the behaviour of dental tissues. It was concluded that FEM is an essential and dependable technique for exploring and addressing questions related to orthodontic biomechanics.

Hong *et al* (2024)[42] conducted a FEM analysis on maxillary incisor torque control using five auxiliary configurations: no auxiliary (control), power ridge, semi-ellipsoid attachment, horizontal rectangular attachment, and horizontal cylinder attachment. The study found that the power ridge provided superior root control, while the semi-ellipsoid attachment was more effective at suppressing labiolingual tipping. However, the power ridge also induced unintended distal twisting, emphasizing the need to match auxiliary choice to treatment goals carefully.

Pede *et al* (2024)[43] conducted a finite element study to evaluate how different sizes and shapes of composite attachments affect tooth movements, specifically rotation, tipping, and torquing, during clear aligner therapy. Using CAD/CAM technology, they modeled 15 upper right canine teeth with various attachment designs and applied a standardized force to simulate movement. The results showed that attachment geometry significantly influenced the biomechanical response: rectangular beveled attachments (3.5 mm × 1.2 mm × 3.5 mm) produced the greatest rotational movement, triangular beveled attachments (5 mm × 0.8 mm × 2 mm) generated the most tipping displacement, and rectangular power ridge attachments (0.5 mm × 0.5 mm × 5 mm) were most effective for torque control. Smaller attachments with less surface area tended to dissipate force more, resulting in greater displacement. The study highlights that optimizing attachment design is critical for effective force application, improving predictability and efficiency in clear aligner treatments.

Al-Samman M *et al* (2024)[44]conducted a study which investigated the accuracy of torque movements in Class II div2 cases, where maxillary incisors retroclined and required torquing. comparing planned inclinations to actual clinical outcomes. Their findings revealed a significant gap between predicted and achieved results, highlighting limitations

in aligner-based torque control. These results echo previous studies that reported similar challenges due to the mechanical constraints of plastic appliances.Notably, their focus on Class II division 2 cases provides insight into a particularly difficult malocclusion subtype. Using 3D digital superimposition, the study confirmed that CAT alone may not reliably deliver intended torque without additional biomechanical aids. This underscores the importance of realistic treatment planning and consideration of adjunctive techniques in complex aligner cases.

Liu *et al* (2025)[45] conducted a comparative investigation into torque expression and its biomechanical effects among three bracket systems: a novel spherical self-ligating bracket with a lock-hook mechanism, passive self-ligating brackets, and conventional brackets. Using three-dimensional finite element models, the study evaluated the efficiency of torque expression and the resulting stress distribution on periodontal tissues. The spherical self-ligating bracket demonstrated superior torque control and more favourable stress distribution compared to the other two systems, suggesting enhanced biomechanical performance and potential clinical advantages. These findings underscore the influence of bracket design on torque efficiency and highlight the importance of optimizing orthodontic appliances to improve treatment outcomes.

Karsli N *et al* (2025)[4]conducted a study on lateral incisor labialization with clear aligners show consistent crown labial and root palatal movement, indicating a tipping effect. Group 6, using both labial and palatal attachments, demonstrated the most controlled movement and minimal aligner deformation, while the attachment-free group showed the greatest crown displacement. Aligner deformation was highest at the incisal edge, decreasing gingivally. Von Mises stresses in the periodontal ligament were concentrated at the gingival level, especially on the palatal side. These findings highlight that dual attachments improve

control and reduce tipping, though increased crown movement raises PDL stress, emphasizing the need for biomechanical precision.

***

Materials And Method

MATERIALS AND METHOD

MATERIALS

This study was conducted using a three-dimensional finite element analysis (3D FEA) approach to investigate the tipping and torquing movement with aligners and different attachment designs of a human maxillary central incisor. The workflow included imaging, geometric modeling, mesh generation, and structural simulation. The resources and tools used in this study are detailed below:

I. **ComputationalResources**

All modeling and simulation tasks were performed on a workstation with the following specifications:

- Processor: 11th Generation Intel® Core™ i5 (2.4 GHz).
- RAM: 8 GB.
- Graphics: 2 GB Dedicated Graphics Card.
- Storage: 1 TB Hard Disk Drive.
- Display: 17-inch Monitor.
- OS: Windows 11.

This configuration was sufficient for handling the 3D modeling, mesh generation, and finite element simulation tasks associated with the study.

II.**CT Scan Acquisition**:

- A spiral (helical) CT scan was performed to obtain high-resolution images of the maxillary central incisor.

- Image Processing Software:

  The acquired scan data in DICOM format was imported into MIMICS software for segmentation and 3D model reconstruction.

- Segmentation and Region of Interest (ROI):

  The region of interest (ROI), including the maxillary central incisor, surrounding alveolar bone, and periodontal ligament, was isolated using grayscale thresholding and manual editing tools within MIMICS.

III. **Surface Extraction and STL Conversion**:

The segmented anatomical structures were converted into 3D surface models, and the geometry was refined before being exported as STL (stereolithography) files for further biomechanical analysis or finite element modelling.

IV.**Reverse engineering and modalities**:

The STL file was imported into the CATIA software for reverse engineering and deck creation. Geometric models were constructed and imported into the HYPERMESH software.

V.**FE meshing using HYPERMESH 2019 different model was created.**

Model no 1- Aligner only without attachment**.**

Model no 2- With horizontal ellipsoidal on labial surface.

Model no 3- With semi-ellipsoid attachment on labial surface.

Model no. 4- with a rectangular power ridge on the labial aspect of the central incisor.

Model no 5- Power ridge on labial as well as palatal aspect.

VI.**Post Processing:**

Displacement in the “Y” axis was extracted stress and strain values were analyzed and compared**.**

VII. **Software Tools:**

Several specialized software tools were used for image processing, model construction, and finite element analysis:

- MIMICS 8.11 (Materialise, Belgium): This software was used to process CT scan data, perform image segmentation, and reconstruct the three-dimensional geometry of the tooth. MIMICS is widely used in biomedical modeling due to its capability to convert medical imaging data into high-fidelity surface models.
- CATIA (Dassault Systems): Utilized for refining the anatomical geometry and reverse engineering of the 3D model, enabling smooth surface generation and precise modeling of complex contours before meshing.
- Hypermesh 2019.0 (Altair HyperWorks): Served as the pre-processing platform to convert the geometric model into a finite element mesh. Hypermesh enabled mesh control, quality checking, and design automation to optimize simulation performance.
- ANSYS 2017.2 (ANSYS Inc., USA): Used for performing the finite element simulations. ANSYS provided the computational environment to apply boundary conditions, simulate forces, and analyze stress and deformation within the tooth model.

VIII. **Boundary conditions:**

- The base of the alveolar bone was fixed in all directions to replicate anchorage within the maxillary arch.
- The aligner was subjected to predefined displacements (e.g., 0.25 mm of labial movement) to simulate the programmed activation step, as done clinically between aligner stages.
- Each model included detailed views (Mesial, Lingual, Front, Distal) and exploded views highlighting individual components (PDL, bone types, teeth, and aligner).

Methodology

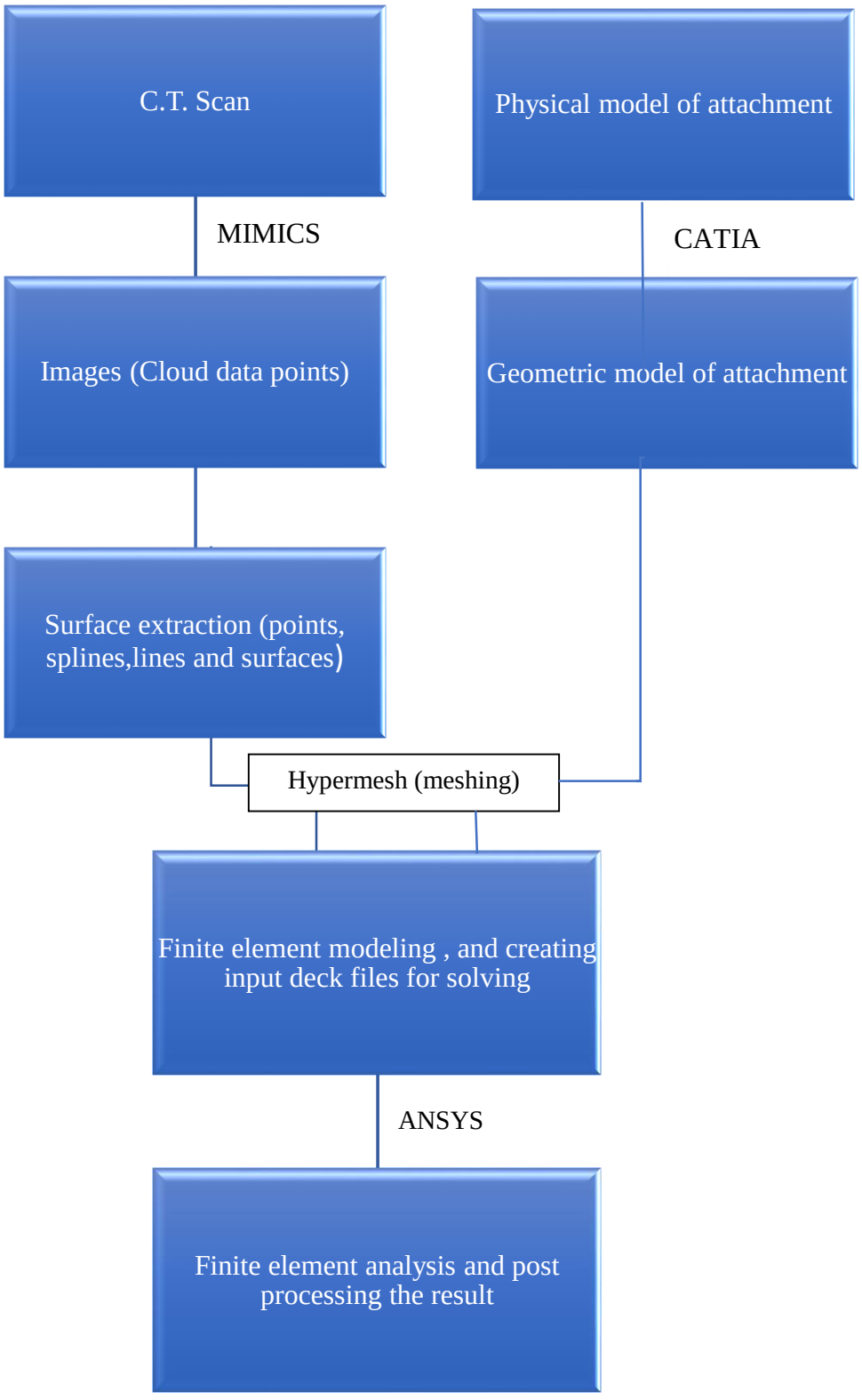

C.T. Scan
Physical model of attachment
MIMICS
CATIA
Images (Cloud data points)
Geometric model of attachment
Surface extraction (points, splines,lines and surfaces)
Hypermesh (meshing)
Finite element modeling , and creating input deck files for solving
ANSYS
Finite element analysis and post processing the result

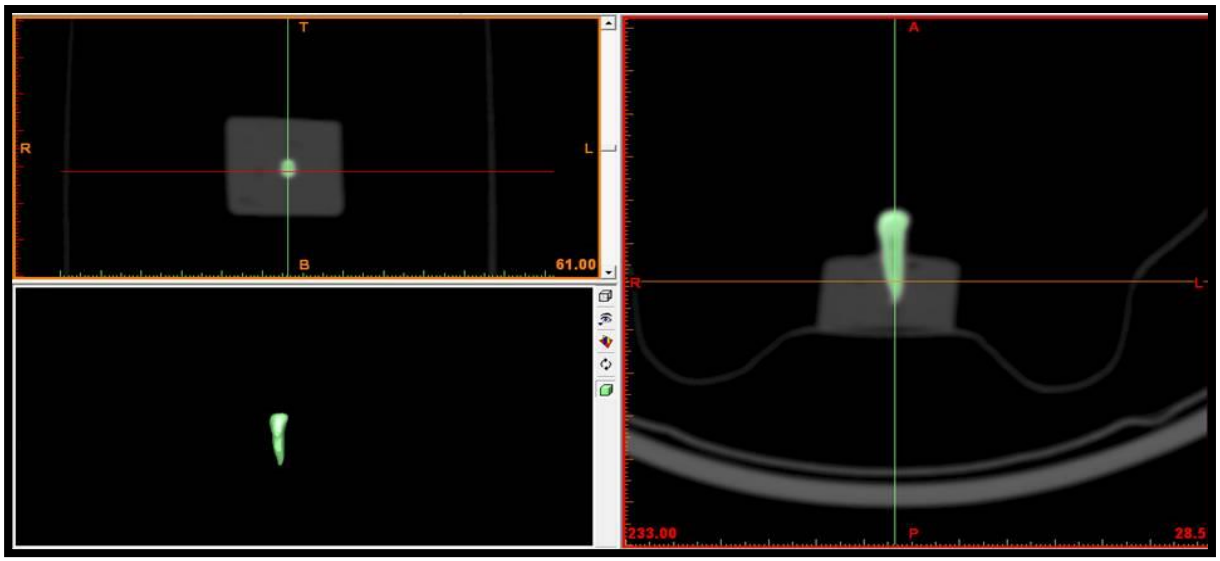
Table 1. Material properties assigned:

S.No	Material	Young's modulus (MPa)	Poisson ratio
1	Alveolar bone	$1.37x10^3$	0.30
2	Tooth	$1.96x10^4$	0.30
3	Composite Attachments	$12.5x10^3$	0.36
4	Plastic Aligner	528	0.36
5	Enamel	$8.41x10^4$	0.33
6	Periodontal ligament(PDL)	$6.9x10^{-1}$	0.45

Table 2. Summary of FE Model Details:

Group	Attachment Type	Nodes	Elements
1	No attachment.	31,256	143,786
2	Ellipsoid composite attachment.	30,277	147,361
3	Semi ellipsoid composite attachment.	27,145	128542
4	Rectangular power ridge.	30,060	146,756
5	Rectangular power ridge on labial as well as palatal aspect.	30115	146834

Figure1-Spiral C.T. scanning machine.



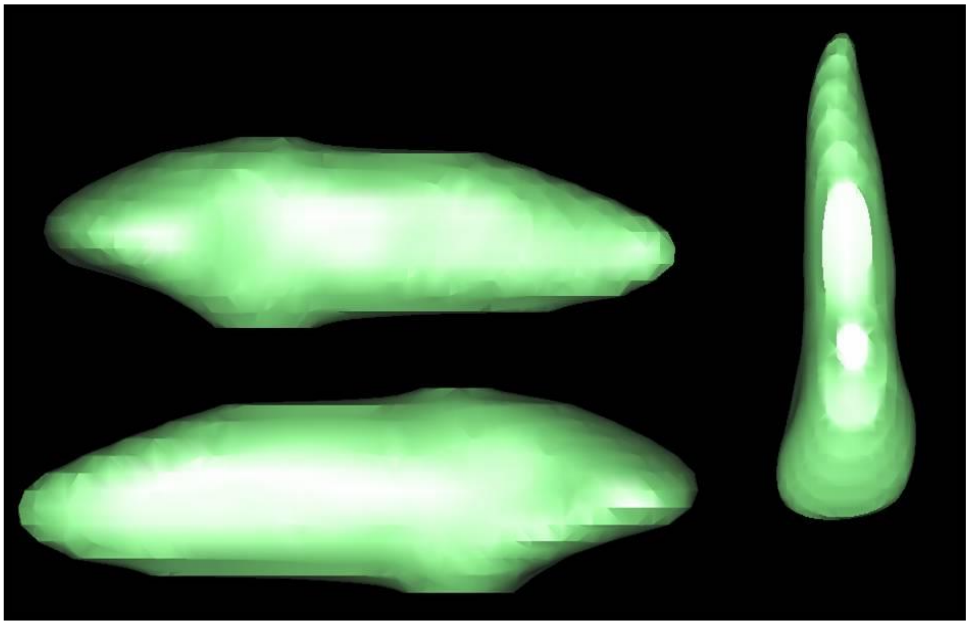


Figure2-CT Scan Image and steps.

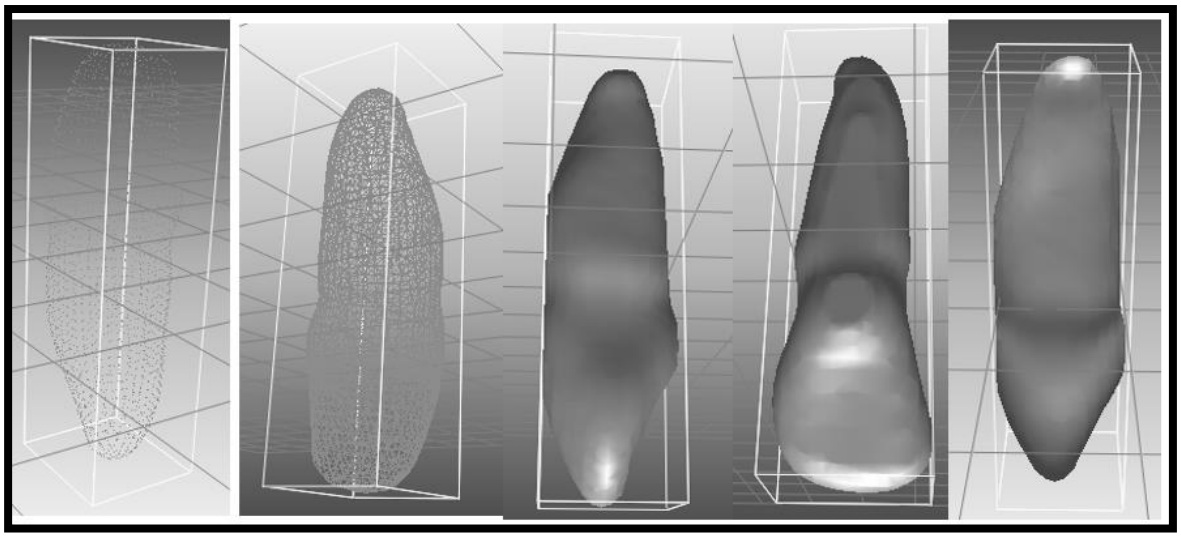


Figure3-Creation of surfaces using STL format from Mimics and Hypermesh Software.

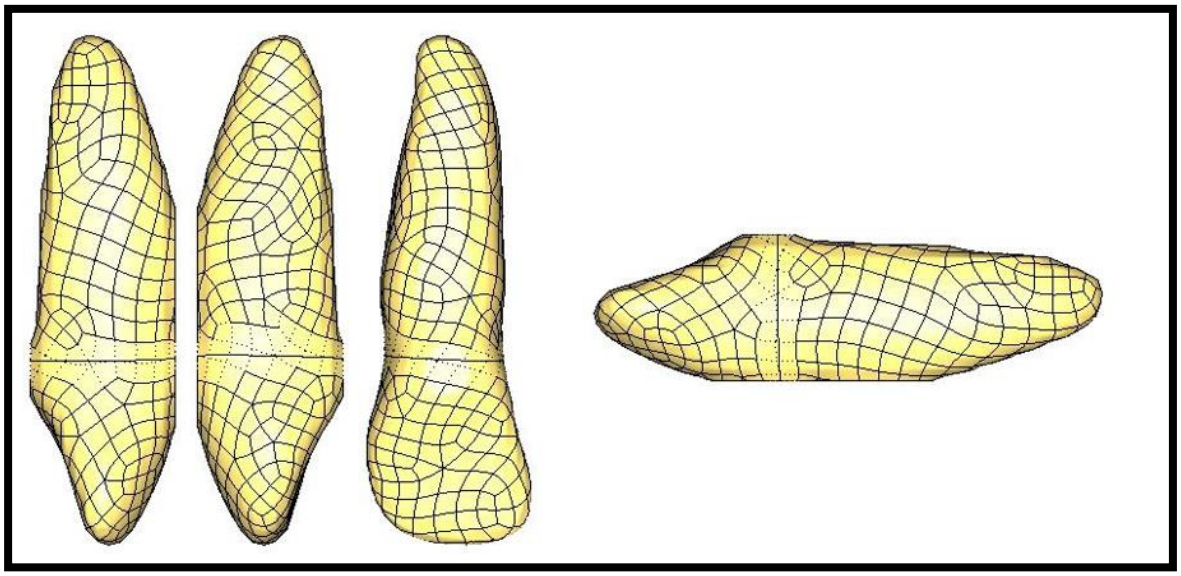


Figure4-Geometric model of Central incisor

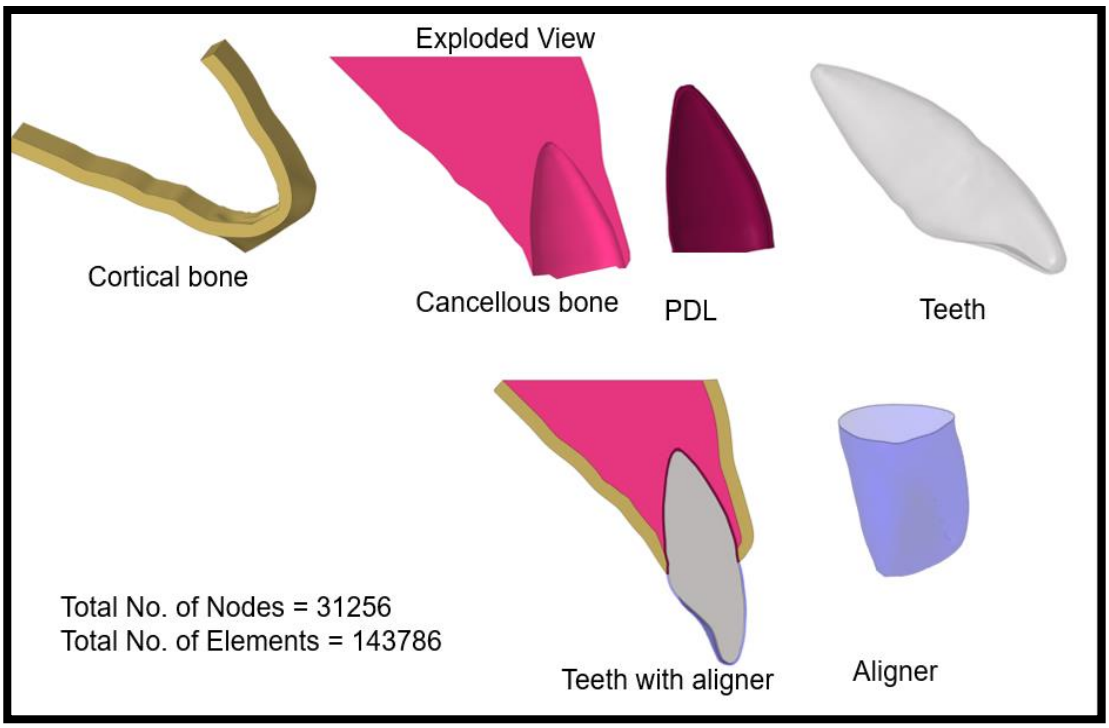


Figure5-Exploded view of aligner without Composite attachment

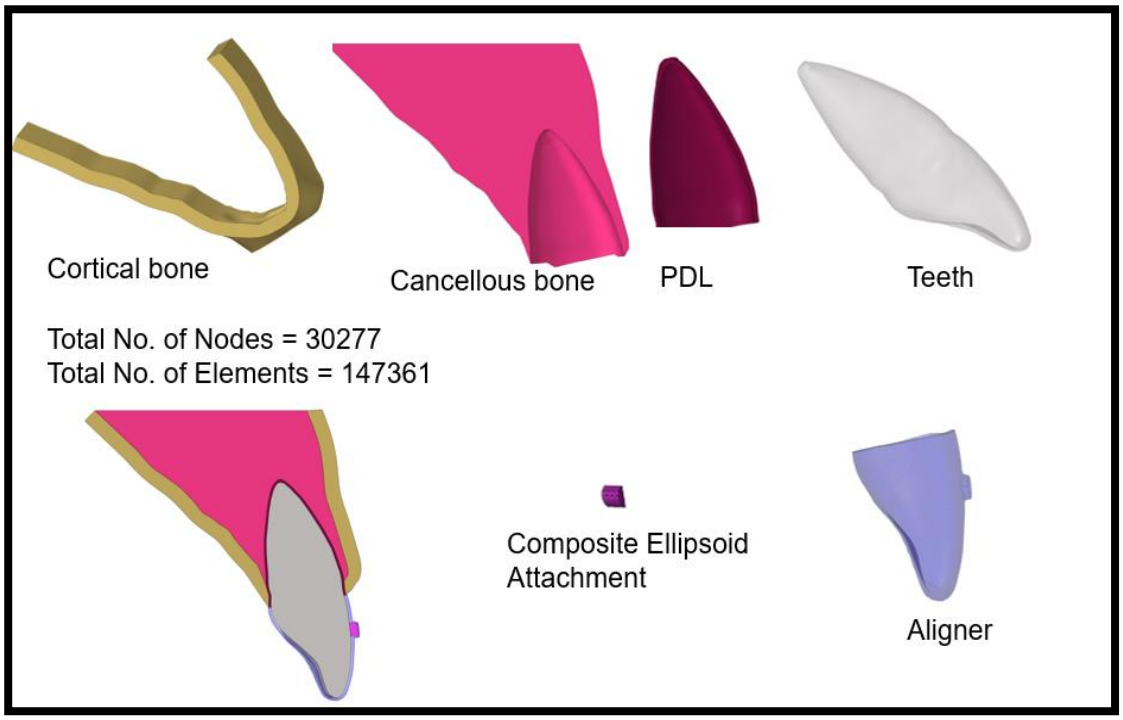


Figure6- Exploded view of model with aligner and ellipsoidal composite attachment

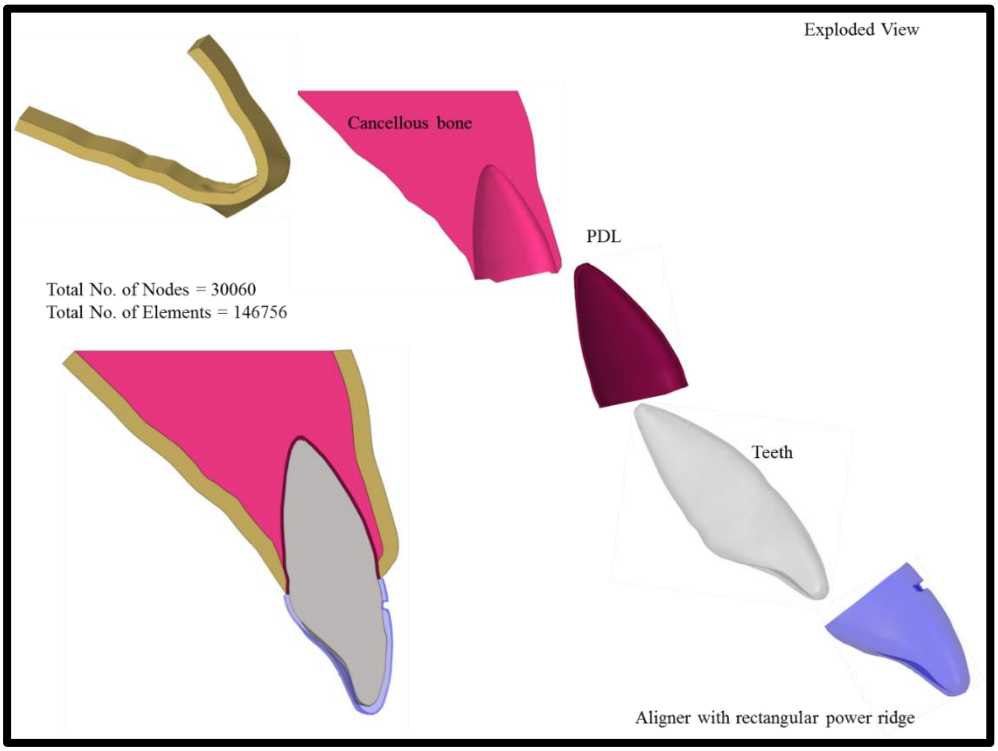


Figure 7- Exploded view of model with aligner and semi-ellipsoid composite attachment

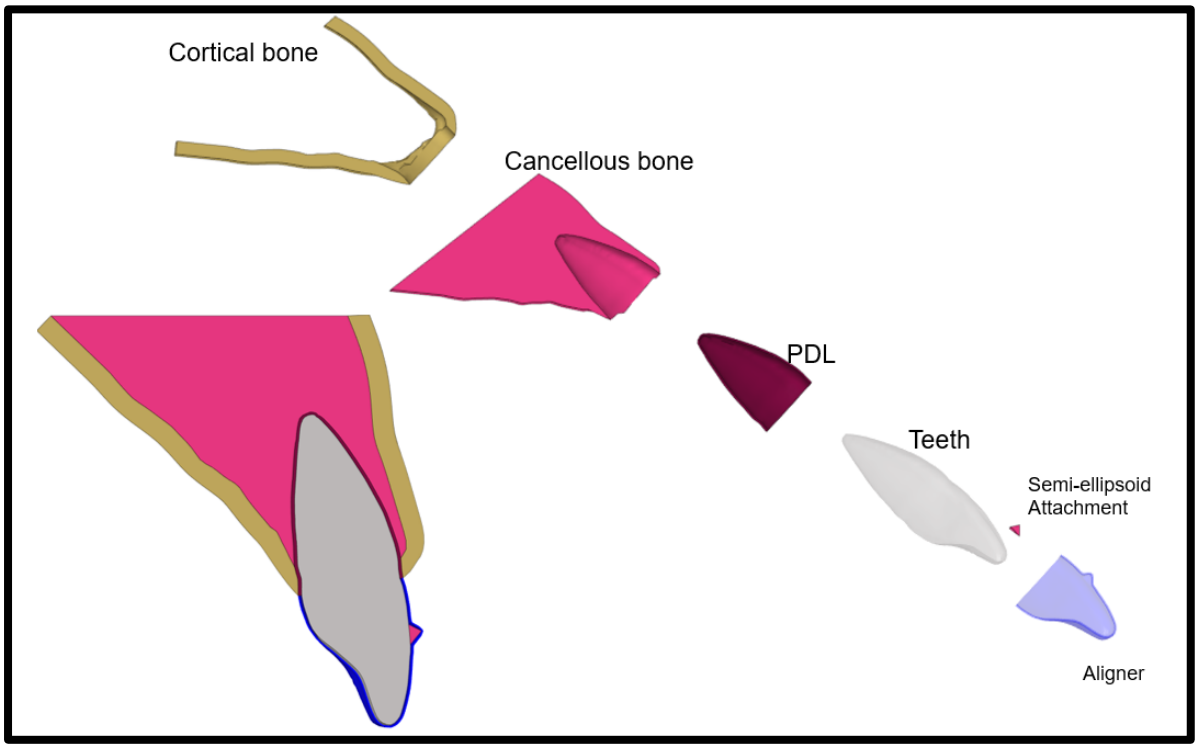


Figure8- Exploded view of model with aligner and rectangular power ridge.

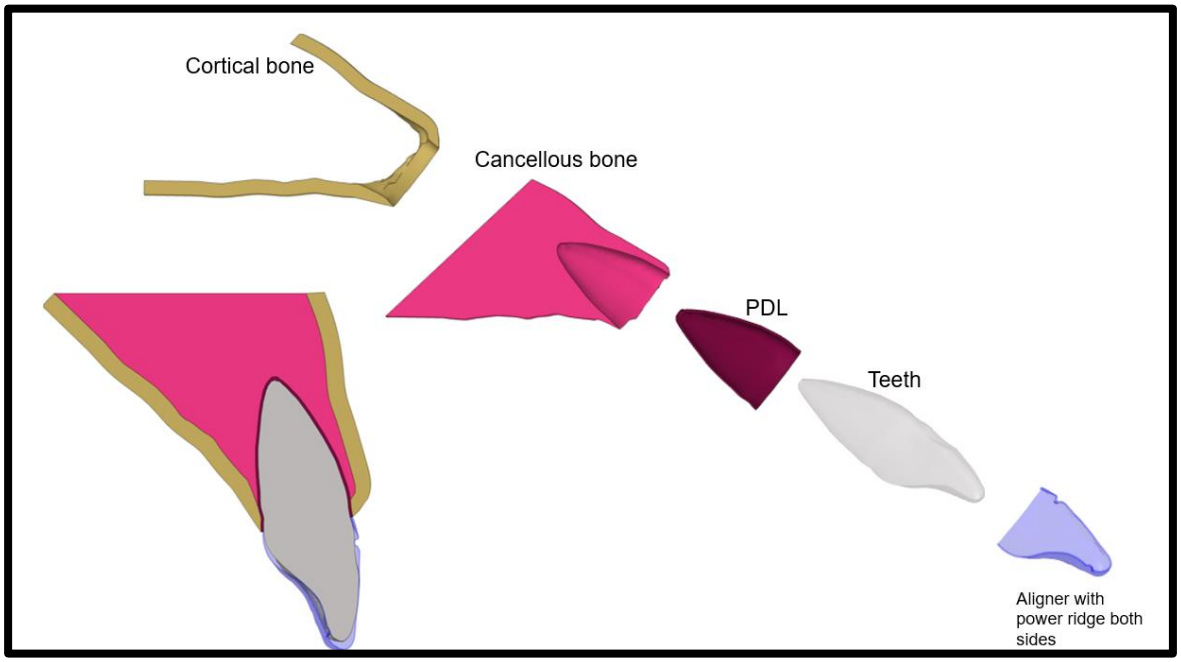


Figure 9- Exploded view of model with aligner and power ridge on both side

***

Results

RESULTS

The present finite element analysis to explain the effectiveness of attachment designs, horizontal ellipsoidal attachment, semi-ellipsoid attachment, inbuilt power ridge on labial aspect, a rectangular power ridge on the labial as well as palatal aspect (dual power ridge), and comparison with an aligner without attachment. The results demonstrate that dual power ridges facilitate a more favorable root centric displacement pattern, reducing the tendency for crown-dominant tipping. Specifically, this configuration yields balanced displacement along the X and Y axes, while maintaining lower Von Mises stress levels within the periodontal ligament (PDL) and teeth compared to attachments on the labial.

Quantitative evaluation reveals that under a 100 gm load, the dual power ridge configuration significantly reduces peak Von Mises stress within the tooth, 2.6 (MPa), while 1.34 (MPa) in PDL, relative to the labial-only ridge, which exhibited elevated stress magnitudes of 6.64 MPa and 2.54 MPa, respectively. Furthermore, the dual ridge system promotes tri-axial root displacement, indicative of controlled bodily tooth movement. These findings suggest an enhanced moment-to-force ratio that effectively converts rotational tipping moments into translational forces.

Displacement metrics further substantiate this conclusion: the labial-only ridge demonstrates predominant Y-axis displacement (0.029 mm) with negligible X-axis root movement, characteristic of uncontrolled tipping mechanics. Conversely, the dual ridge design generates measurable Y-axis displacement (0.028 mm at 100 gm), consistent with physiologic torque and root movement. Among evaluated attachment morphologies, semi-ellipsoid forms exhibit minimal displacement and stress but limited efficacy in torque generation.

Table 3: Von Mises Stress and Tooth Displacement (0.8 mm Aligner Thickness).

S.No	Model	Load (gm)	Teeth Stress (MPa)	PDL Stress (MPa)	Crown Displacement (mm)	Root Displacement (mm)
1	**Aligner only (without attachment)**	50	3.51	1.38	0.017	0.001
		100	5.65	2.22	0.022	0.001
2	**Horizontal Ellipsoidal Attachment**	50	3.57	1.06	0.012	0.001
		100	5.95	2.13	0.023	0.002
3	**Semi-Ellipsoidal Attachment**	50	2.40	0.32	0.003	0.000
		100	6.00	0.579	0.008	0.001
4	**Power Ridge on Labial Surface**	50	4.12	0.849	0.012	0.001
		100	6.64	2.54	0.029	0.003
5	**Power Ridge (Labial & Palatal) Surface**	50	1.23	0.672	0.000	-0.014
		100	2.60	1.34	0.000	0.028

1. **Von Mises stress on the teeth and periodontal ligament (PDL) under both 50 gm and 100 gm loads.**

i. **Aligner Only (Without Attachment).**

In the aligner-only configuration without any attachment, the recorded Von Mises stress on the tooth at 50 gm load was 3.51 MPa. In contrast, the corresponding stress on the periodontal ligament (PDL) was 1.38 MPa. Under a higher load of 100 gm, the stress values increased to 5.65 MPa on the tooth and 2.22 MPa on the PDL. These values represent the baseline stress conditions when no auxiliary mechanical elements, such as attachments, are used with the aligner, showing how the load translates directly to the dental structures.

ii. **Horizontal Ellipsoidal Attachment.**

For the configuration involving a horizontal ellipsoidal attachment, the Von Mises stress measured on the tooth at a 50 gm load was 3.57 MPa, which is slightly higher than that observed in the aligner-only model. The stress recorded on the PDL under the same load was 1.06 MPa. When the applied load was increased to 100 gm, the stress on the tooth rose to 5.95 MPa, while the stress on the PDL was 2.13 MPa. These values reflect the mechanical response of the system with horizontal ellipsoidal attachment under both lower and higher force applications.

iii. **Semi-Ellipsoidal Attachment.**

In the semi-ellipsoidal attachment model, the Von Mises stress on the tooth at 50 gm loading was recorded at 2.40 MPa, which is the lowest among all models at this load level. The corresponding PDL stress was 0.32 MPa, also the lowest at this force level. Under an increased load of 100 gm, the stress on the tooth increased significantly to 6.00 MPa, while the stress on the PDL was 0.579 MPa.

iv. **Power Ridge on Labial Surface Only.**

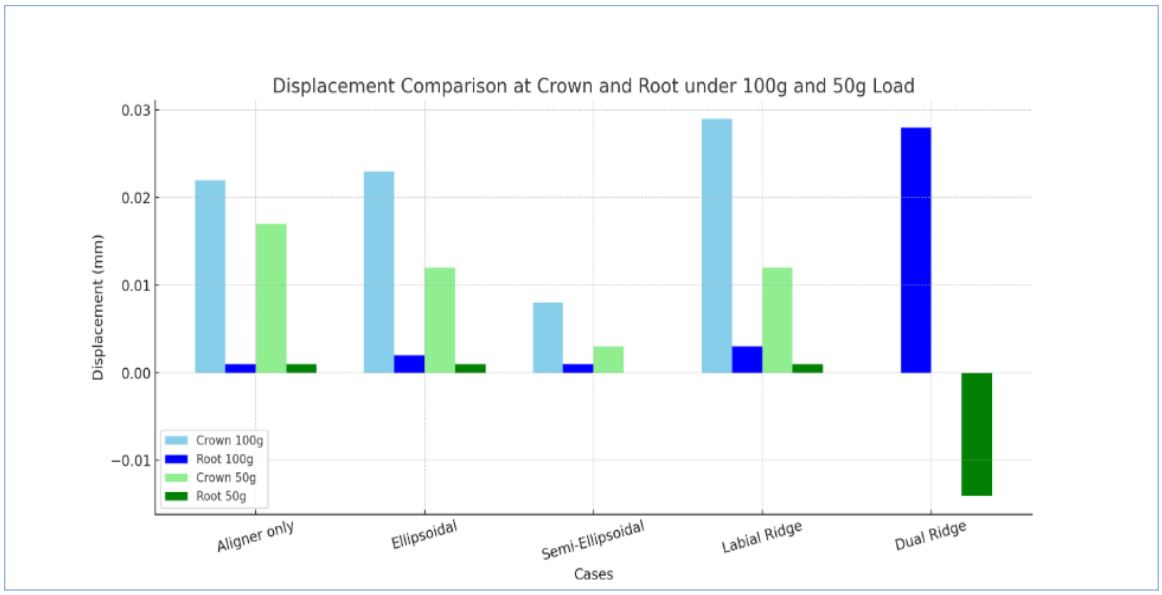
When a rectangular power ridge was present on the labial surface only, the Von Mises stress recorded on the tooth at 50 gm load was 4.12 MPa, and the PDL stress was 0.849 MPa. Upon increasing the load to 100 gm, the stress on the tooth reached 6.64 MPa, which is the highest stress value among all configurations at this load level. The stress on the PDL also increased correspondingly to 2.54 MPa, which is the maximum among all models for 100 gm loading in the PDL. These numerical values reflect the mechanical stress distribution observed in the labial-only power ridge condition under both loading conditions.

v. **Dual Power Ridge (Labial & Palatal Surfaces)**

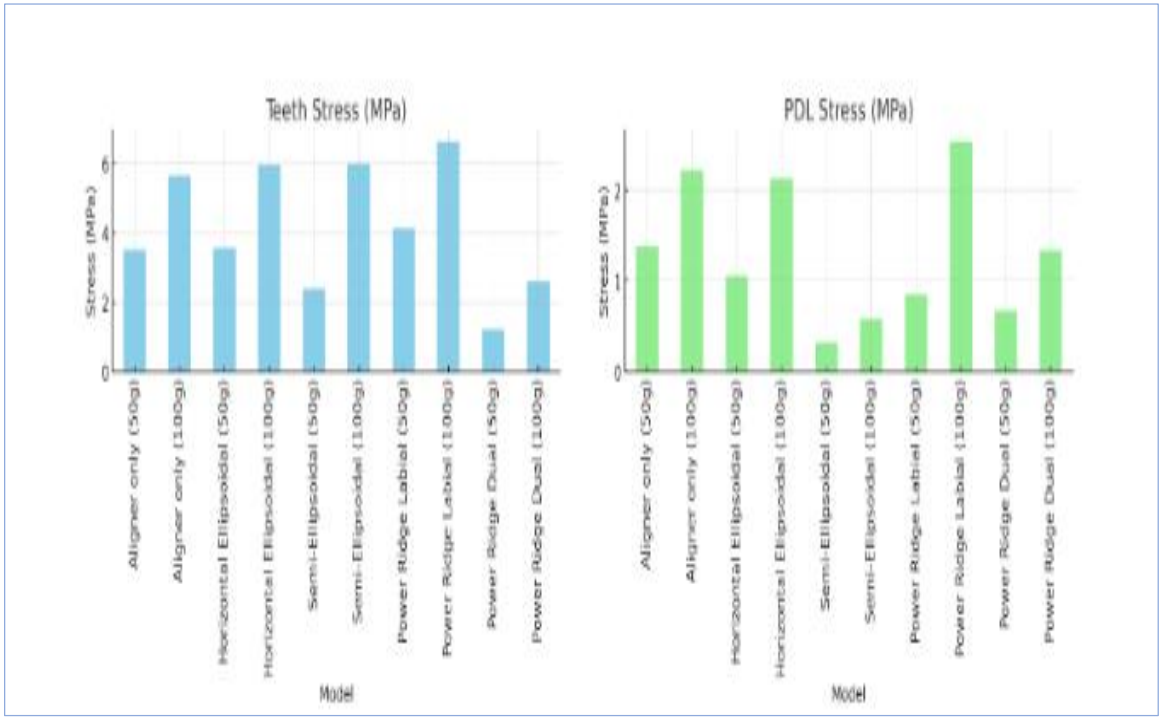
In the configuration with dual power ridges located on both the labial and palatal surfaces, the Von Mises stress on the tooth under 50gm load was 1.23 MPa, and the stress on the PDL was 0.672 MPa. When the load was increased to 100 gm, the stress on the tooth was 2.60 MPa, and the PDL stress was 1.34 MPa. These data represent the stress magnitudes in the tooth and PDL resulting from a symmetrically placed dual ridge system subjected to low and high force levels.

Table 4: Displacement at the crown of teeth and the root of teeth, load applied is 100 gm and 50 gm.

Case	Description	Load (gm)	Displacement (y- axis) (mm)	
			Crown	**Root**
1	**Aligner only without Attachment**	100	0.022	0.001
		50	0.017	0.001
2	**Horizontal ellipsoidal attachment**	100	0.023	0.002
		50	0.012	0.001
3	**Semi-Ellipsoidal Attachment**	100	0.008	0.001
		50	0.003	0.000
4	**Power ridge on the labial surface**	100	0.029	0.003
		50	0.012	0.001
5	**Power Ridge (Labial & Lingual)**	100	0.000	0.028
		50	0.000	-0.014



Graph 1. Displacement Comparison at Crown and Root under 100 gm and 50 gm



Graph 2. Stress comparison graph on Teeth and PDL.

2. Crown and root displacement values under 50 gm and 100 gm loading conditions, for all five models of aligner configurations

i. Aligner Only (Without Attachment)

In the aligner-only configuration with no attachment, the displacement observed at the crown under a 50 gm load was 0.017 mm, while the corresponding root displacement was 0.001 mm. Under the 100 gm load, the crown displacement increased to 0.022 mm, with the root displacement remaining constant at 0.001 mm. This configuration provides a reference dataset for comparing displacement behavior in the absence of attachments.

ii. **Horizontal Ellipsoidal Attachment**

With a horizontal ellipsoidal attachment, the recorded crown displacement was 0.012 mm at 50 gm load and 0.023 mm at 100 gm. The root displacement was 0.001 mm under 50 gm, increasing slightly to 0.002 mm under 100 gm.

iii. **Semi-Ellipsoidal Attachment**

In the case of the semi-ellipsoidal attachment, crown displacement was the lowest among all models, recorded as 0.003 mm under 50 gm and 0.008 mm under 100 gm loading. The root displacement was 0.000 mm at 50 gm, and 0.001 mm at 100 gm.

iv. **Power Ridge on Labial Surface Only**

When using a rectangular power ridge on the labial surface only, the crown displacement at 50 gm was 0.012 mm, and increased to 0.029 mm under 100 gm the highest crown displacement recorded across all models. The root displacement was 0.001 mm at 50 gm and increased to 0.003 mm at 100 gm, which is also the peak root displacement observed in the data set.

v. Dual Power Ridge (Labial & Palatal Surfaces)

In the dual ridge model with both labial and palatal rectangular power ridges, the crown displacement under a 50 gm load was 0.000 mm, and remained 0.000 mm under 100 gm. In contrast, the root displacement was 0.014 mm at 50 gm, indicating displacement in the opposite direction, and 0.028 mm at 100 gm m, which is the highest recorded root displacement in the data. This configuration thus displays a unique distribution between crown and root movement values, as per the recorded measurements.

“y” axis

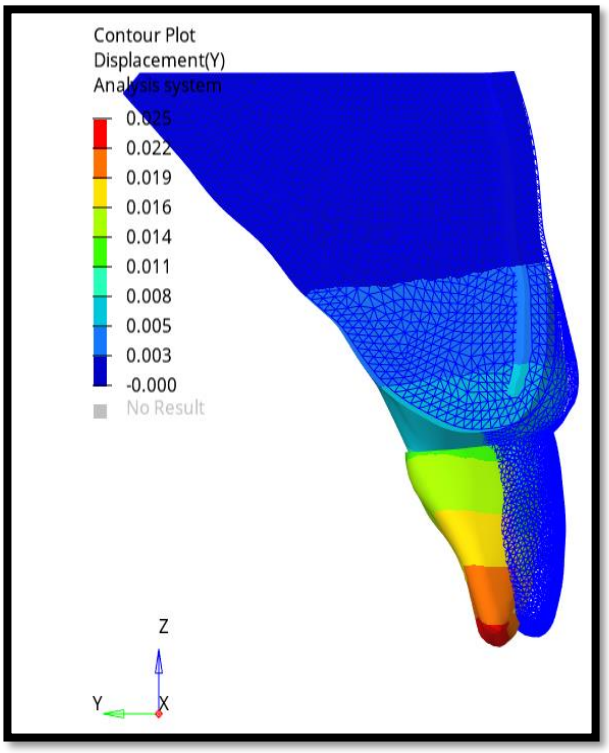


Figure 10- Displacement contour in Maxillary Central Incisor with only Thermoplastic Aligner with 100 gm load –no attachment

Von-Mises stress

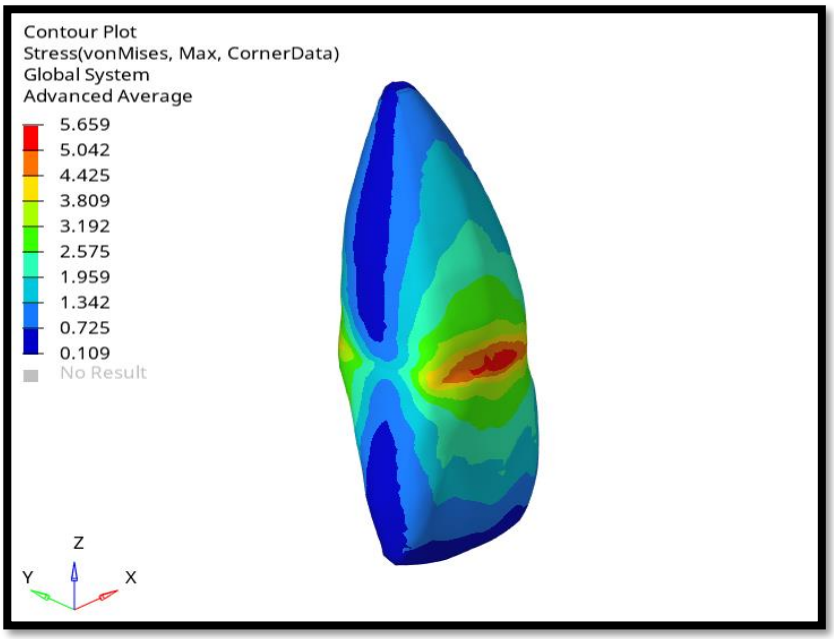


Figure 11- Stress contours of Thermoplastic Aligner on maxillary central incisors with 100 gm load in tooth –no attachment

Von-mises stress **Maximum Principal Stress**

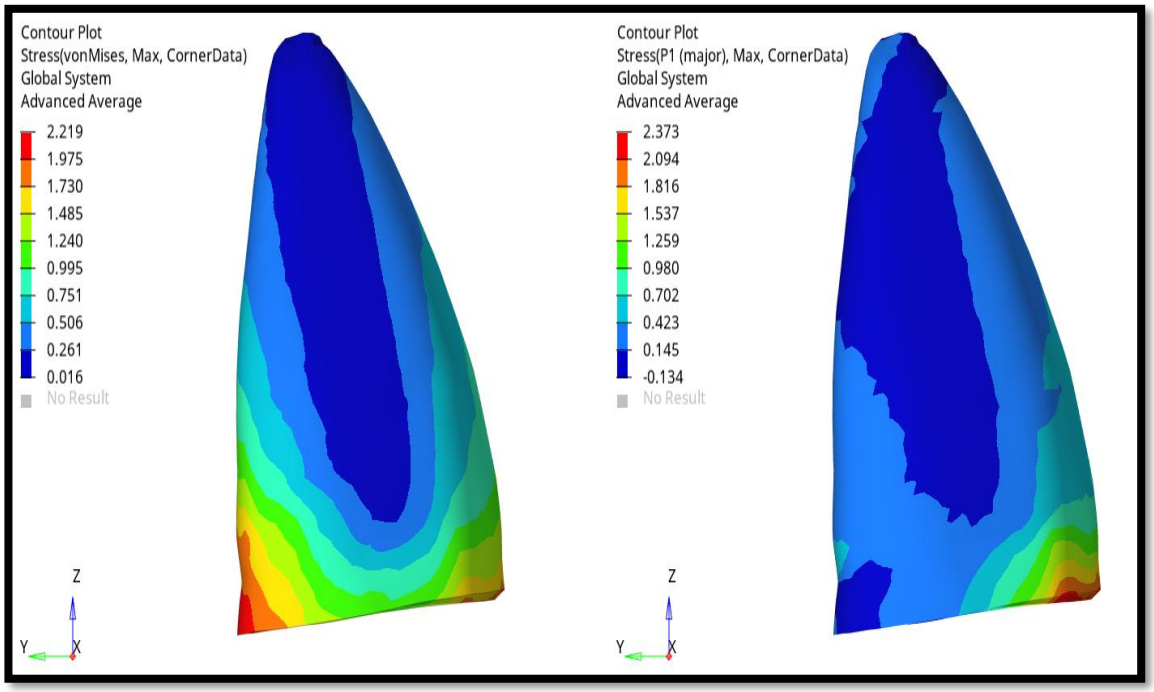


Figure 12- Stress contours of Thermoplastic Aligner on maxillary incisors PDL area with 100 gm load in tooth –no attachment

Von-mises **Displacement**

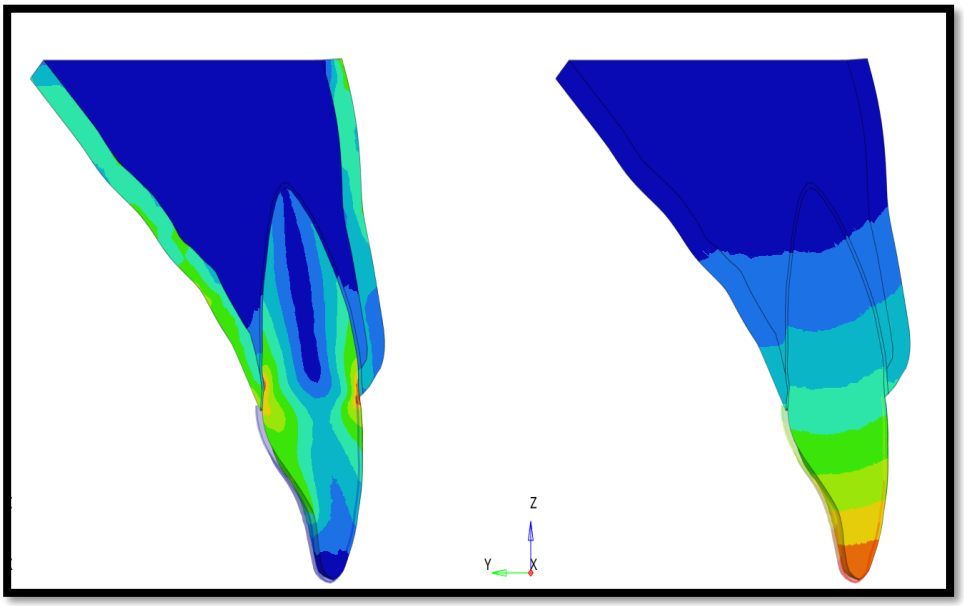


Figure 13- Displacement and Stress contours in the sectional view of the aligner on the maxillary incisors area with maximum Von-Mises stress without attachment, Aligner with 100 gm load in tooth –no attachment

“y” axis

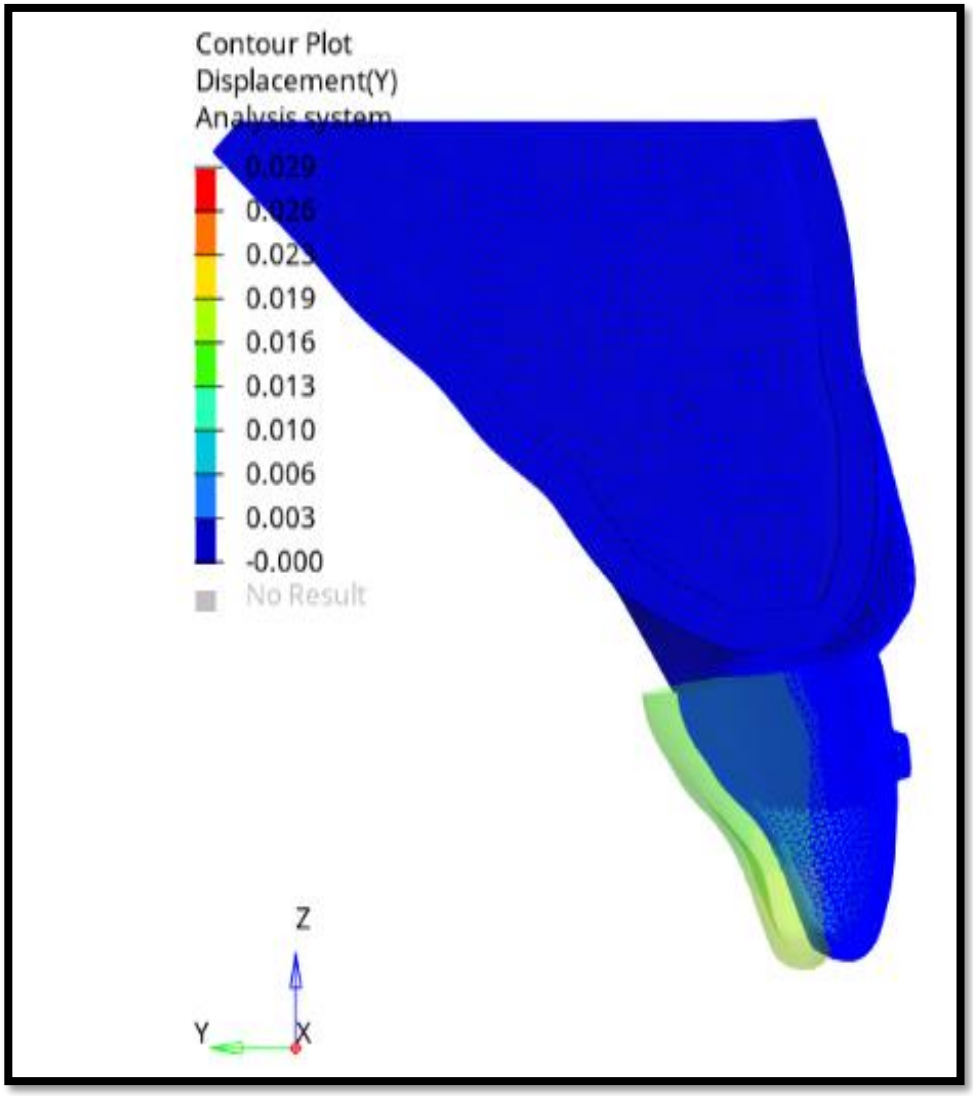


Figure 14- Displacement contour of Thermoplastic Aligner in Maxillary Central Incisor with Horizontal Ellipsoid Attachment at 100gm load.

“y” axis

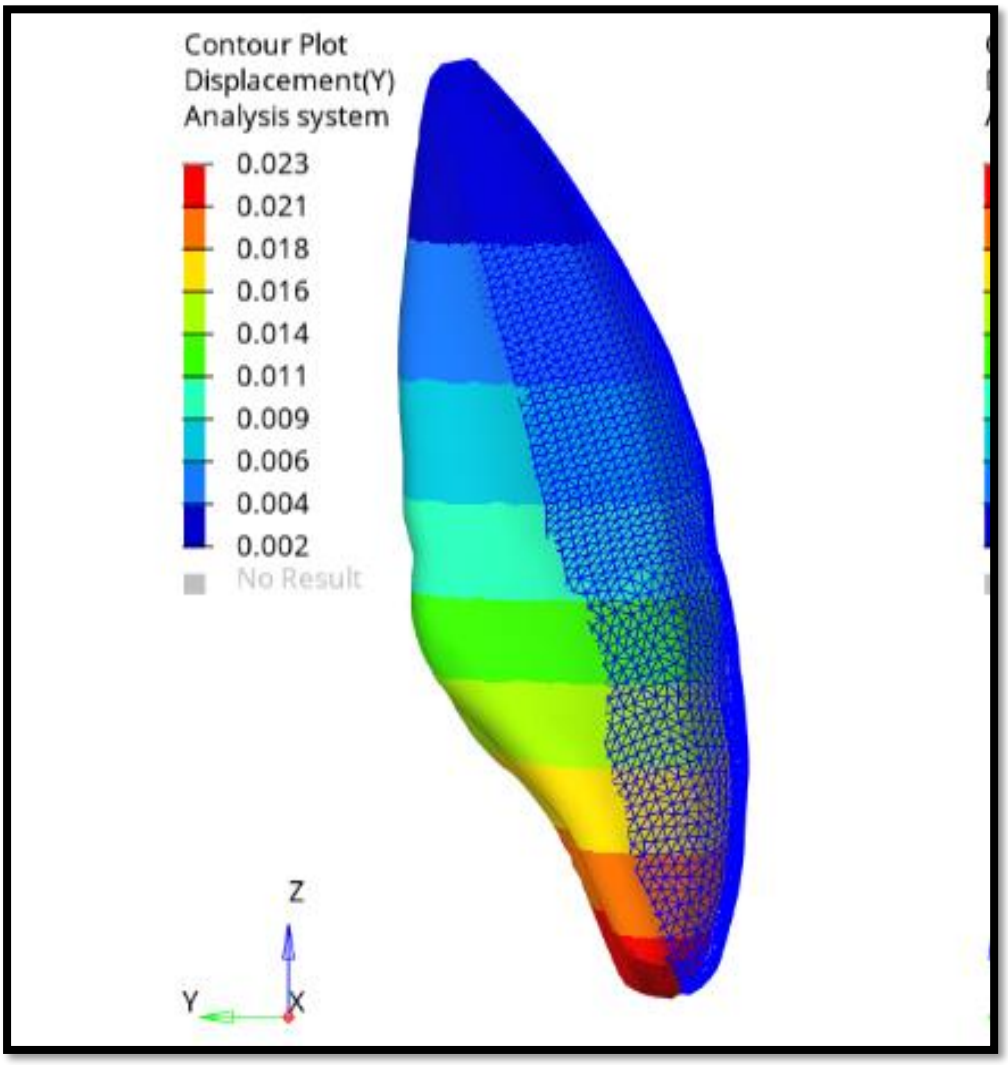


Figure 15- Displacement contour of thermoplastic aligner in maxillary central incisor with Horizontal Ellipsoid Attachment with 100 gm load.

Von-mises stress **Maximum Principal Stress**

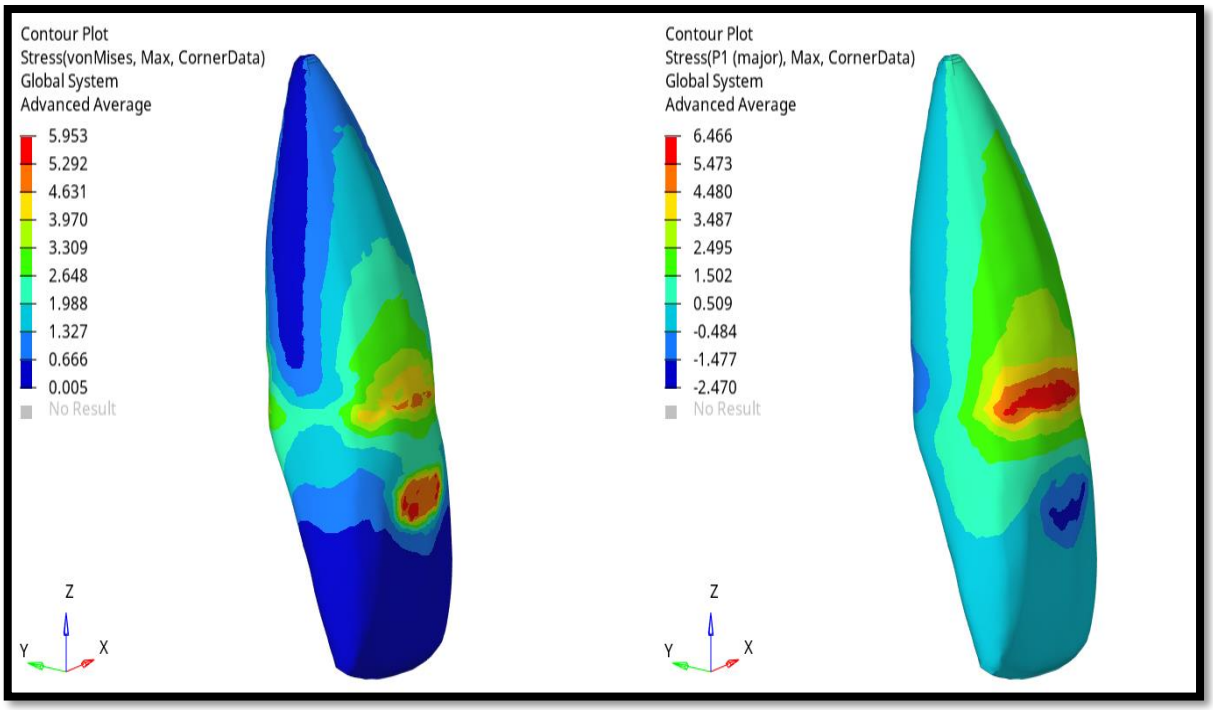


Figure 16- Stress contours of thermoplastic aligner on maxillary central incisors with Horizontal Ellipsoid attachment with 100 gm load in the tooth

Von-mises stress **Maximum Principal Stress**

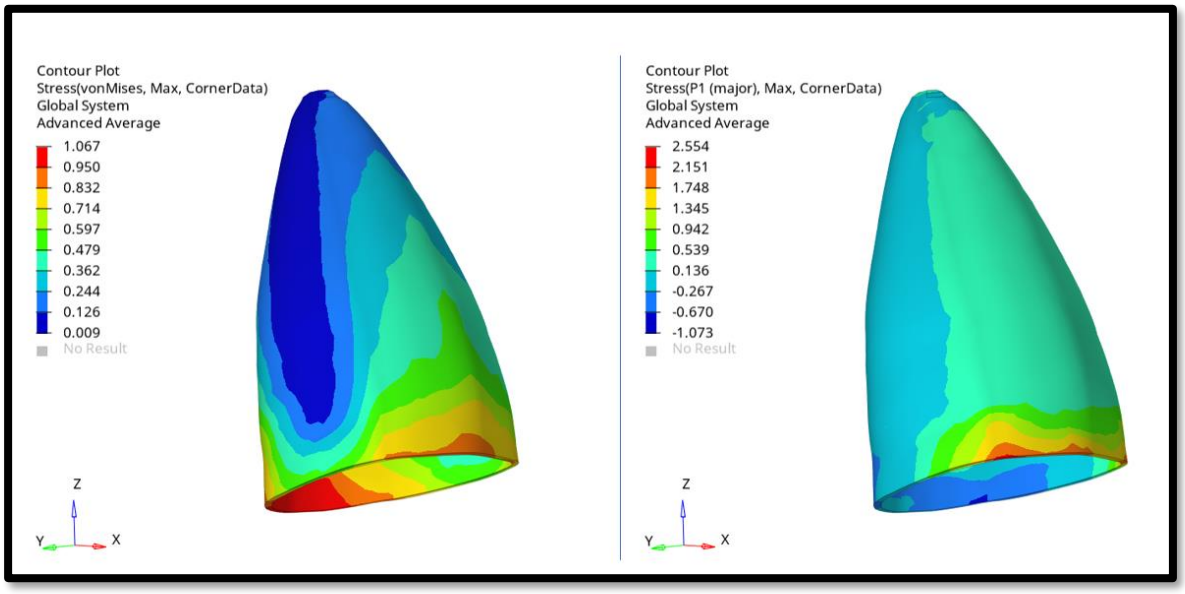


Figure 17- Displacement contour of thermoplastic aligner in maxillary central incisor with Horizontal Ellipsoid Attachment with 100 gm load

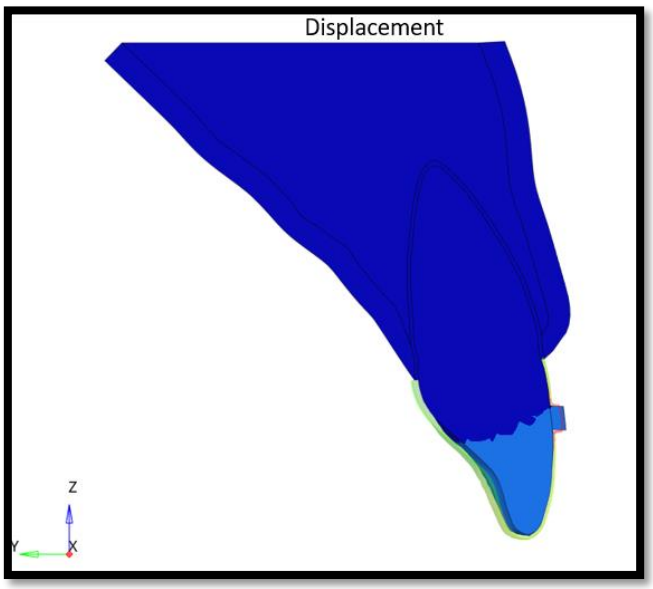


Figure 18- Displacement contour of thermoplastic aligner in maxillary central incisor with Horizontal Ellipsoid Attachment with 100 gm load.

Von-mises stress **Maximum Principal Stress**

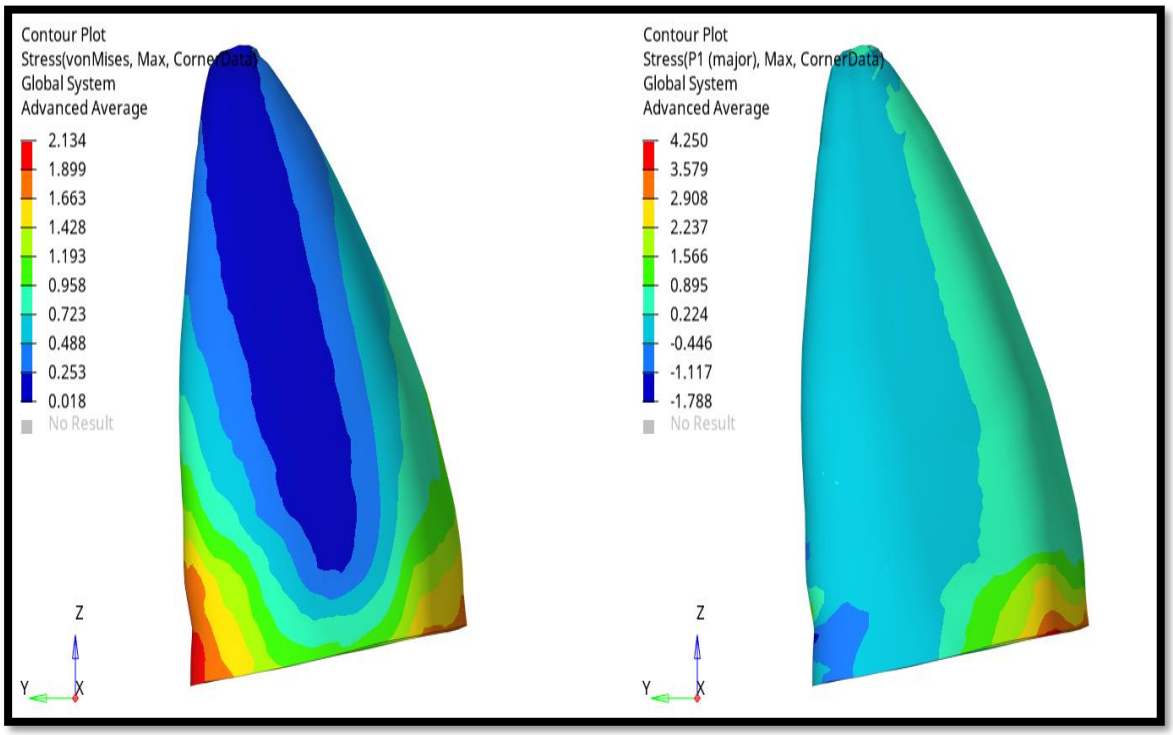


Figure 19- Stress contours of Thermoplastic aligner at PDL on maxillary central incisors with Horizontal Ellipsoid attachment with 100 gm load in tooth.

Von-mises stress **Displacement**

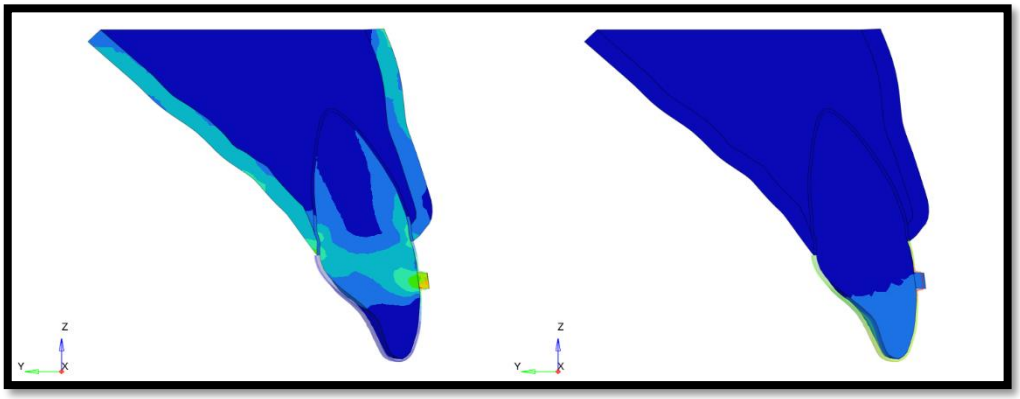


Figure 20- Displacement and Stress contours of the Thermoplastic Aligner in sectional view with Horizontal Ellipsoid attachment, with the aligner on the maxillary incisors area with 100 gm load in the tooth.

“y” axis

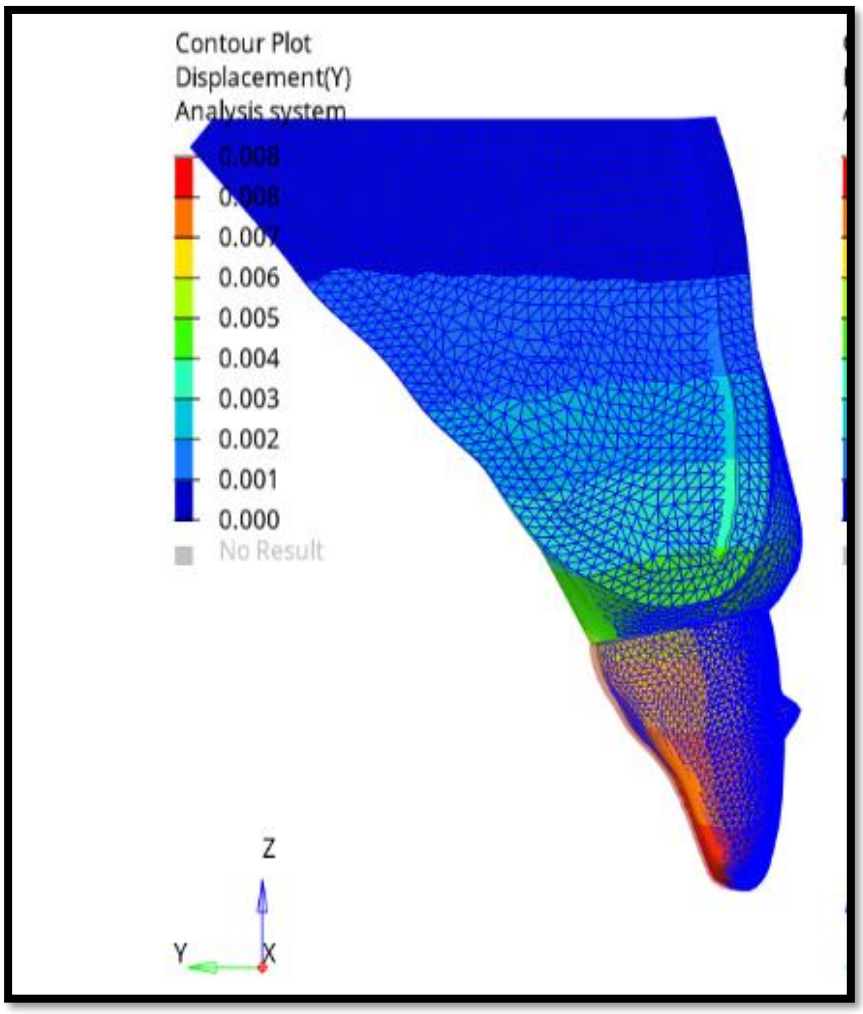


Figure 21- Displacement contour of Thermoplastic Aligner in Maxillary Central Incisor with only Semiellipsoidal Attachment at 100 gm load.

“y” axis

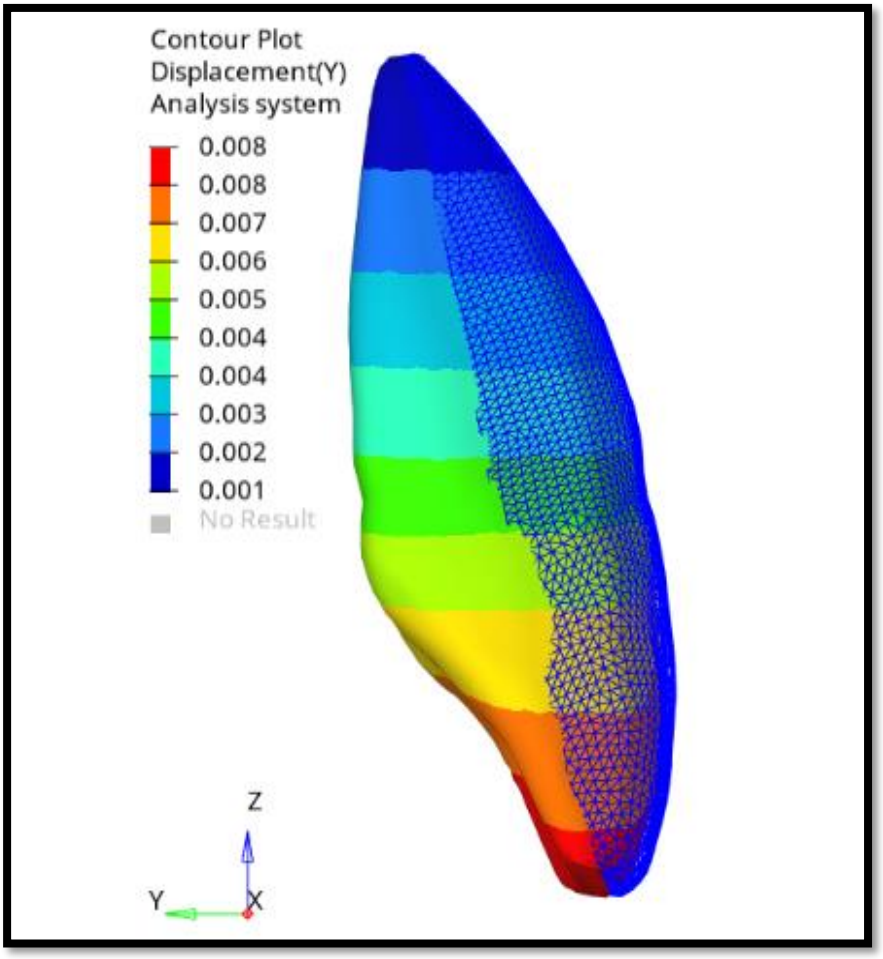


Figure 22- Displacement contour of thermoplastic aligner in maxillary central incisor with Semiellipsoidal Attachment with 100 gm load.

Von-Mises stress

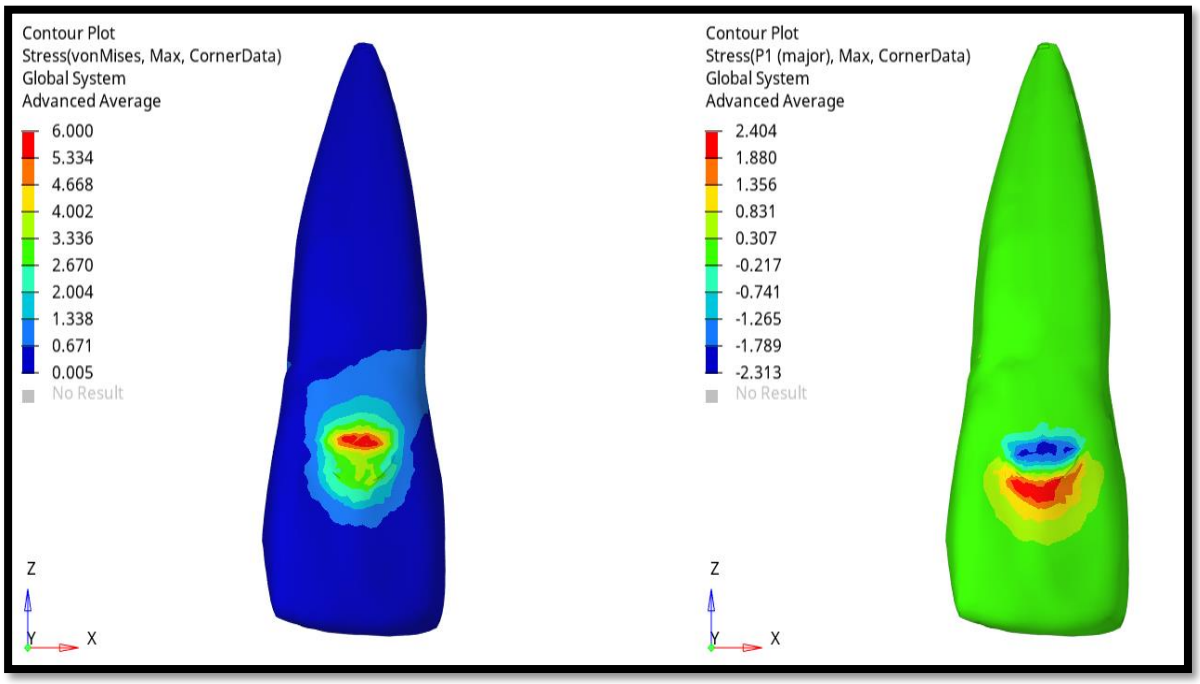


Figure 23- Stress contours of thermoplastic aligner on maxillary central incisors with Semiellipsoidal attachment with 100 gm load in tooth.

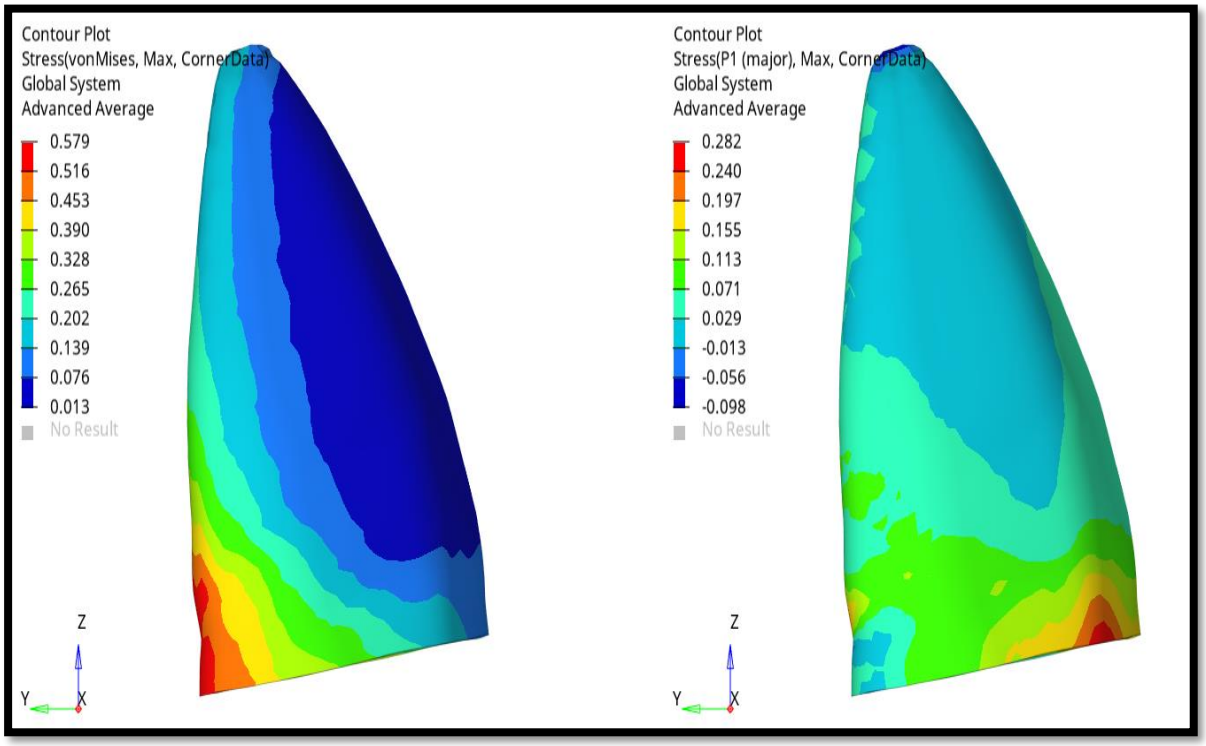


Figure 24-Stress contours of the Thermoplastic aligner at PDL on maxillary central incisors with Semiellipsoidal attachment with 100 gm load in the tooth.

Von-Mises stress **Displacement**

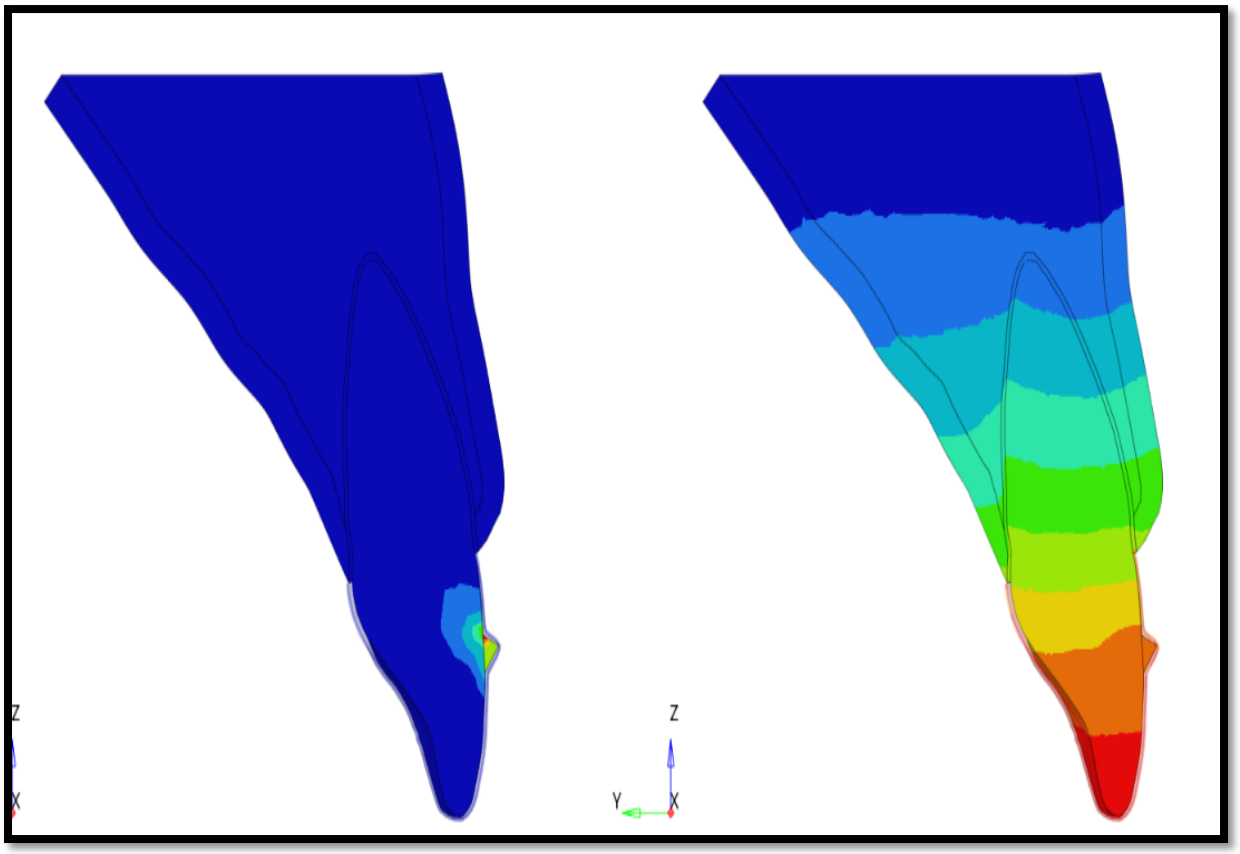


Figure 25- Displacement and Stress contours of the Thermoplastic Aligner with Semiellipsoidal attachment, with 100 gm load in the tooth.

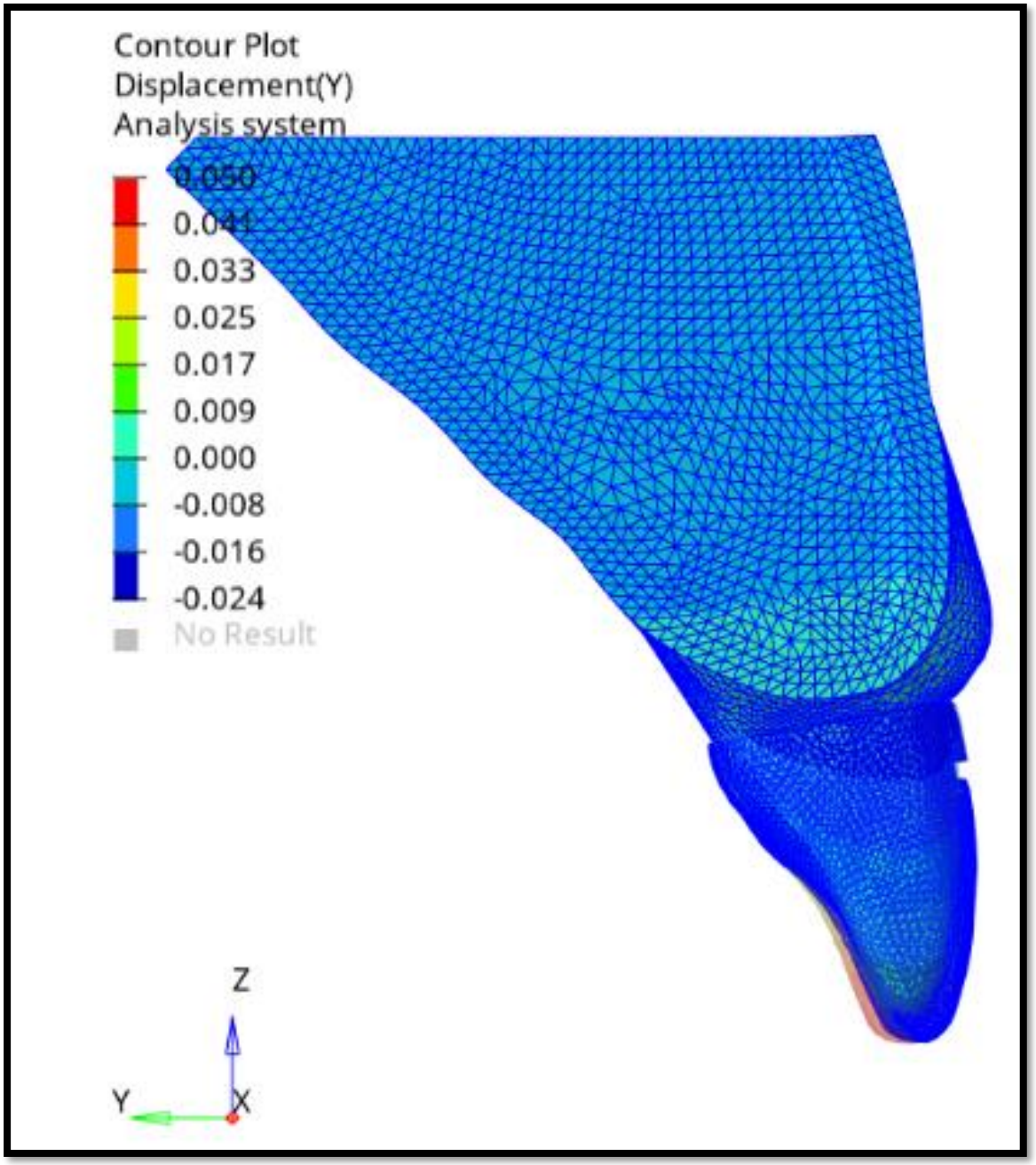


Figure 26- Displacement contour of Thermoplastic Aligner in Maxillary Central Incisor with only Rectangular Power ridge at 100 gm load.

“y” axis

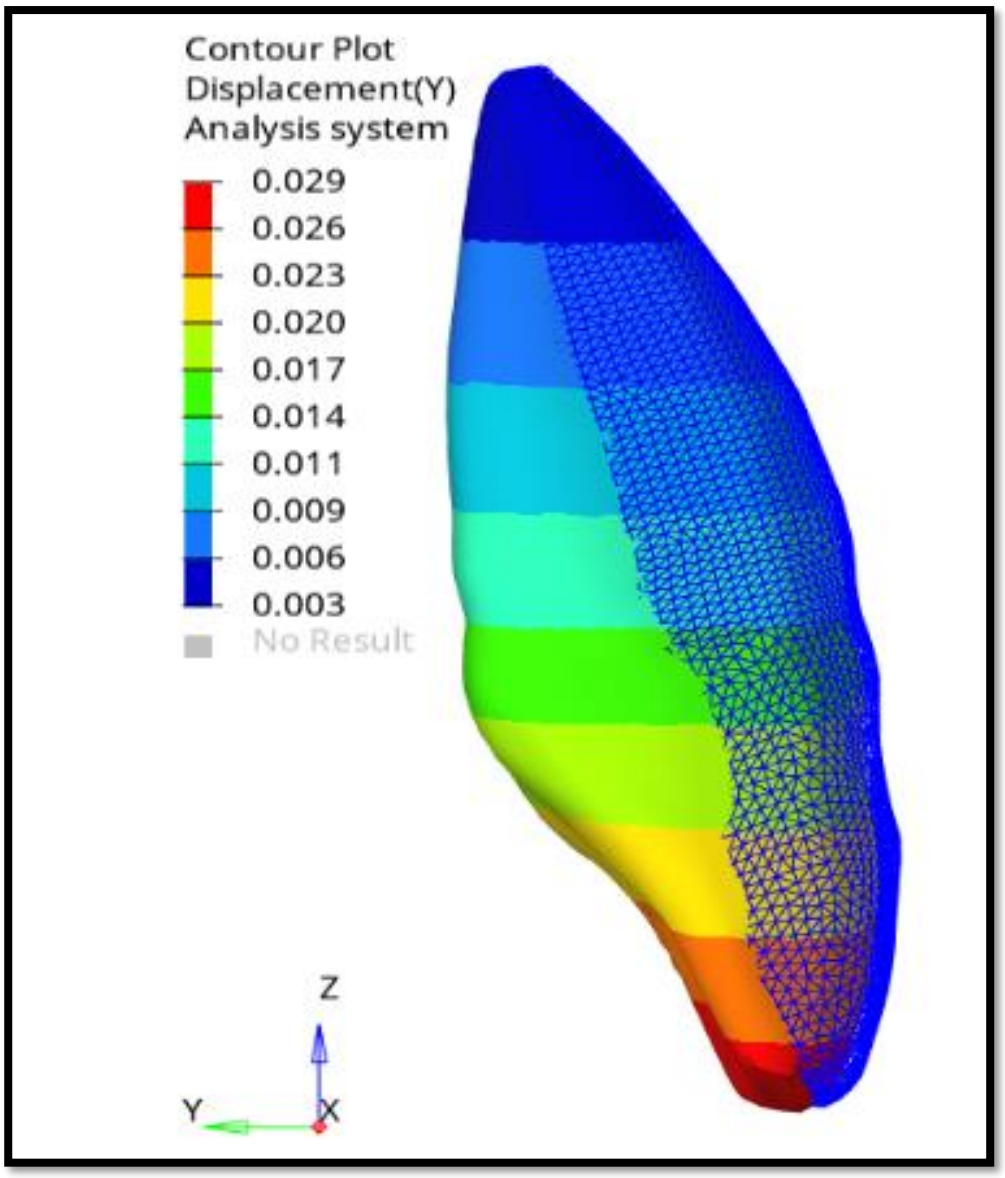


Figure 27-Displacement contour of Thermoplastic Aligner in maxillary central incisor with Rectangular Power ridge Aligner with 100 gm load

Von-Mises stress **Maximum principal stress**

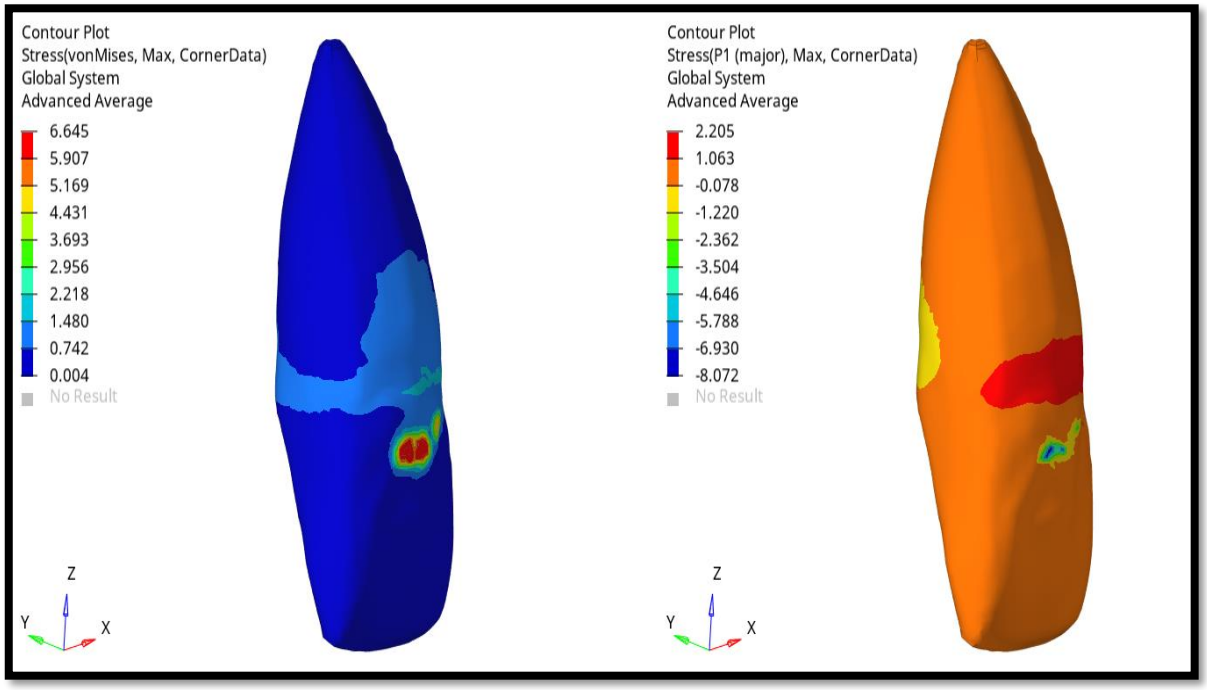


Figure 28- Stress contours of thermoplastic aligner on maxillary incisors with Rectangular Power ridge with 100 gm load in tooth

Von-Mises stress **Maximum Principal Stress**

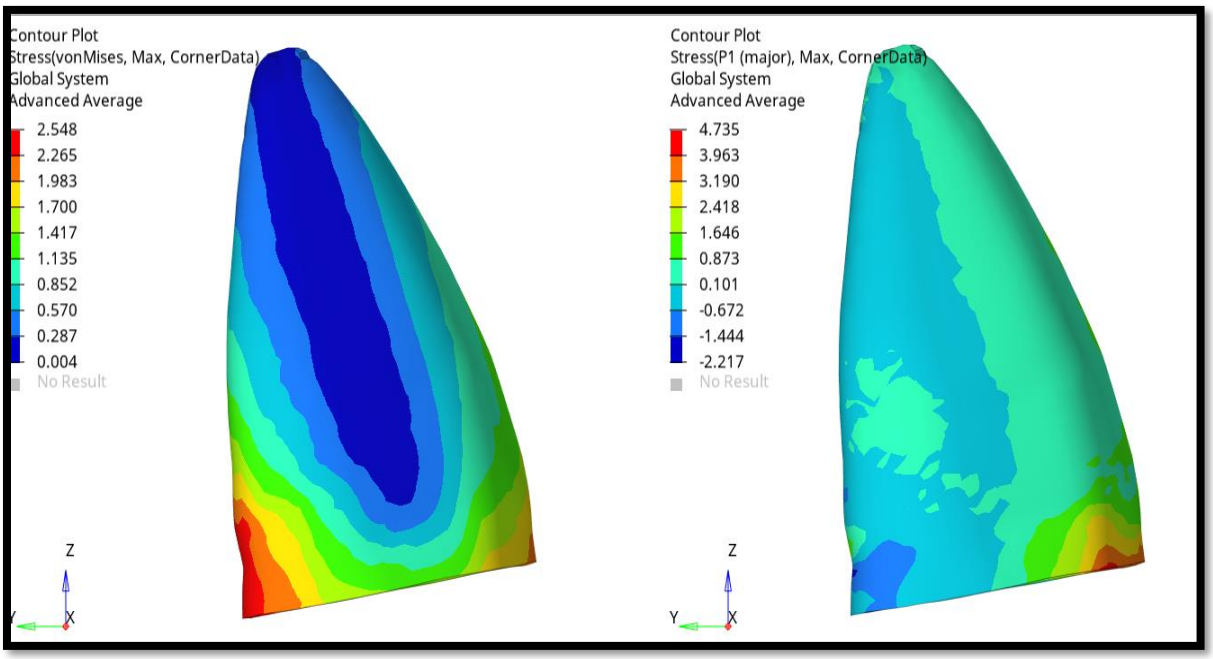


Figure 29- Stress contours of Thermoplastic aligner at PDL on maxillary central incisors with Rectangular Power ridge with 100 gm load in tooth

Von-Mises stress **Displacement**

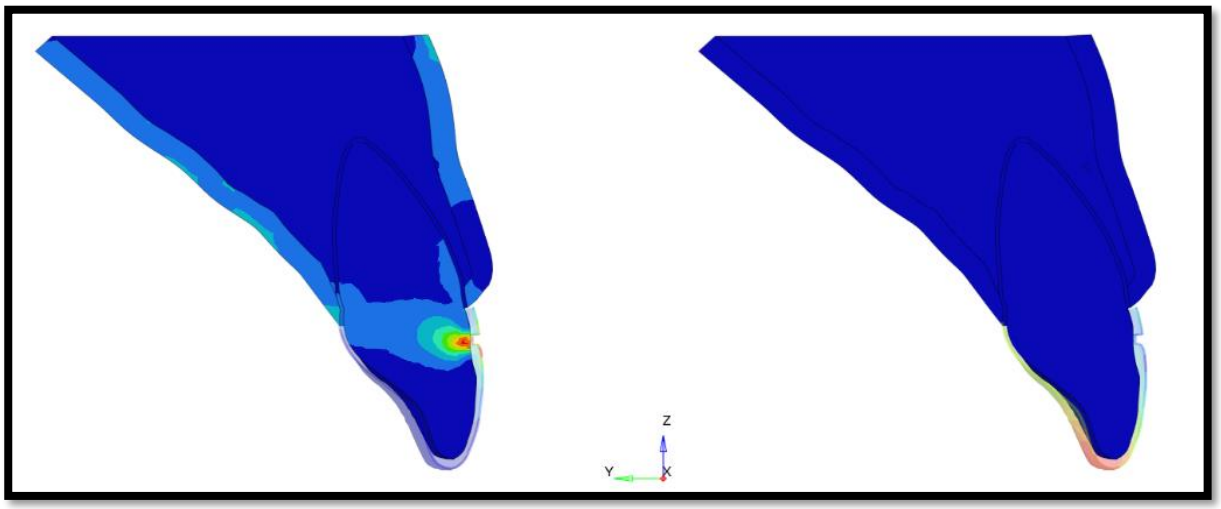


Figure 30- Displacement and Stress contours of the Thermoplastic Aligner in a sectional view with a rectangular power ridge attachment, with 100 gm load in the tooth.

"y" axis

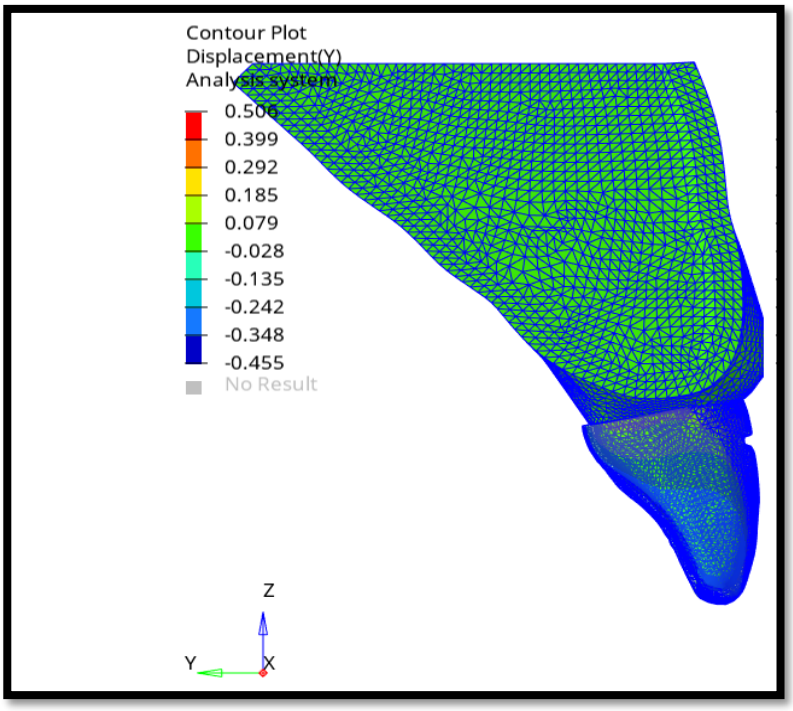


Figure 31-Displacement contour of Thermoplastic Aligner with Rectangular Power ridge on both Labial and Lingual side in Maxillary Central Incisor with at 100 gm load.

“y”-axis

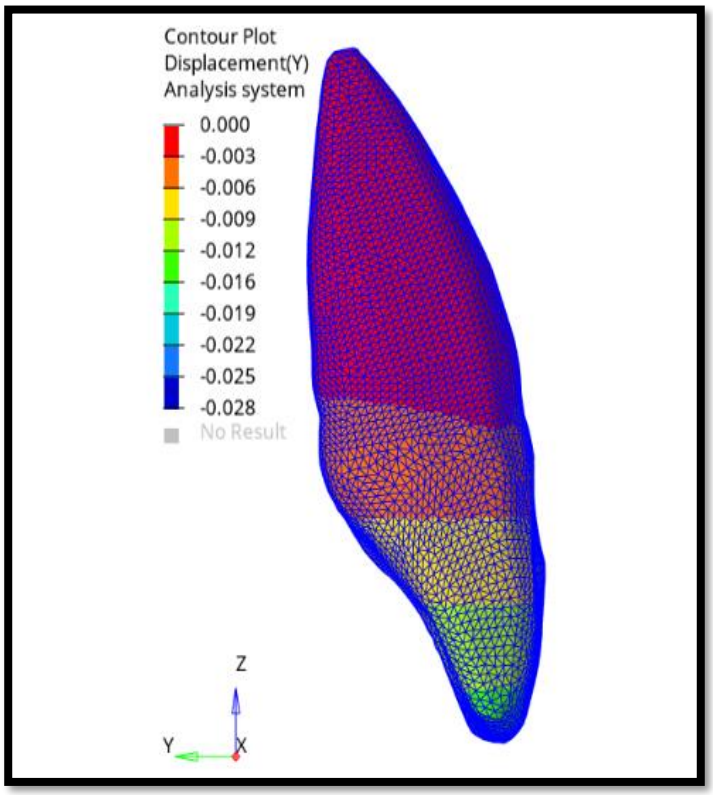


Figure 32- Displacement contour of thermoplastic aligner in maxillary central incisor with Rectangular Power ridge with 100 gm load.

Von-Mises stress

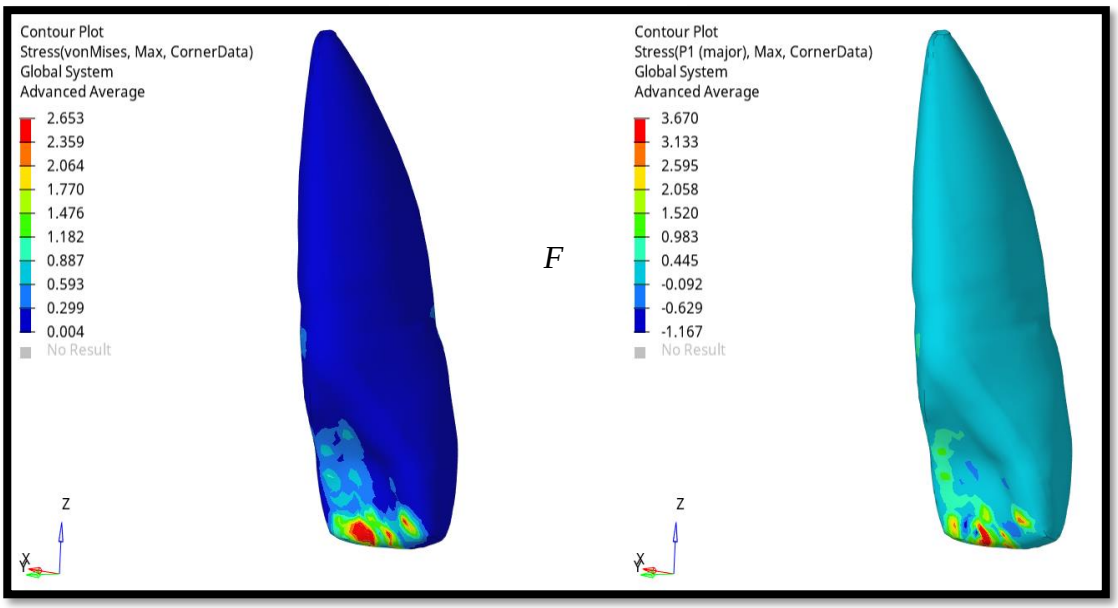


Figure 33- Stress contours of thermoplastic aligner on maxillary central incisors with rectangular power ridge attachment with 100 gm load in tooth

Von-Mises stress **Maximum Principal Stress**

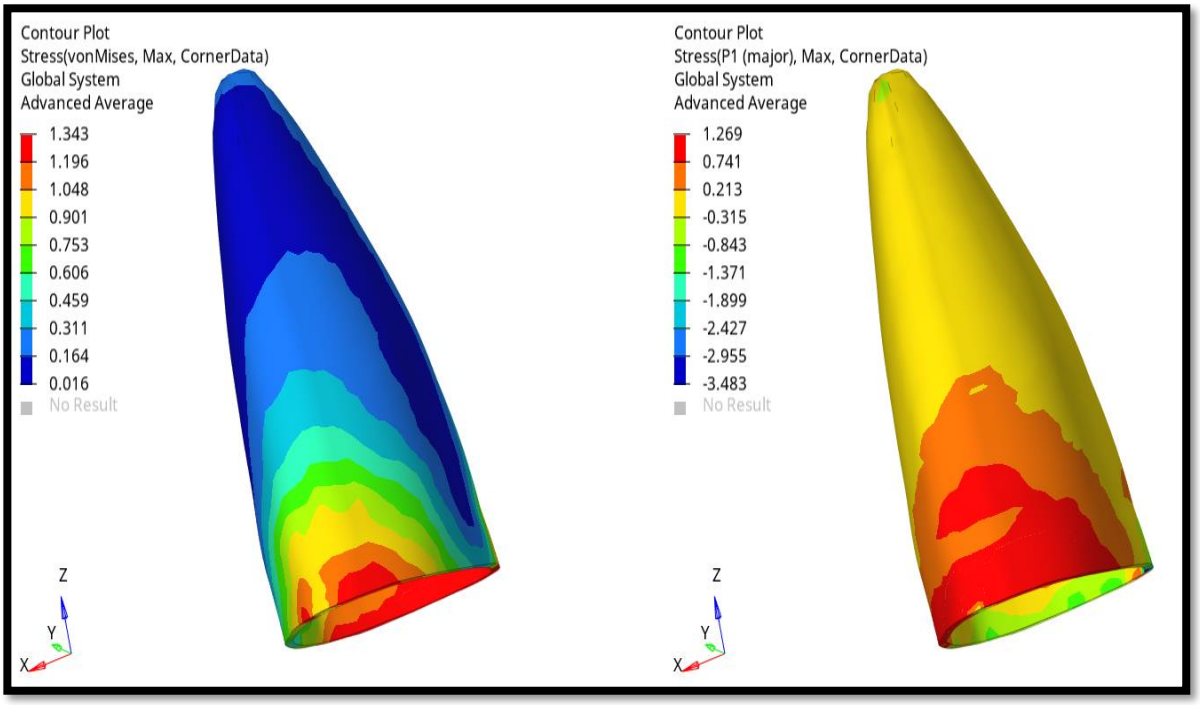


Figure 34 - Stress contours of Thermoplastic aligner at PDL on maxillary central incisors with rectangular power ridge attachment with 100 gm load in tooth

Von-Mises stress **Displacement**

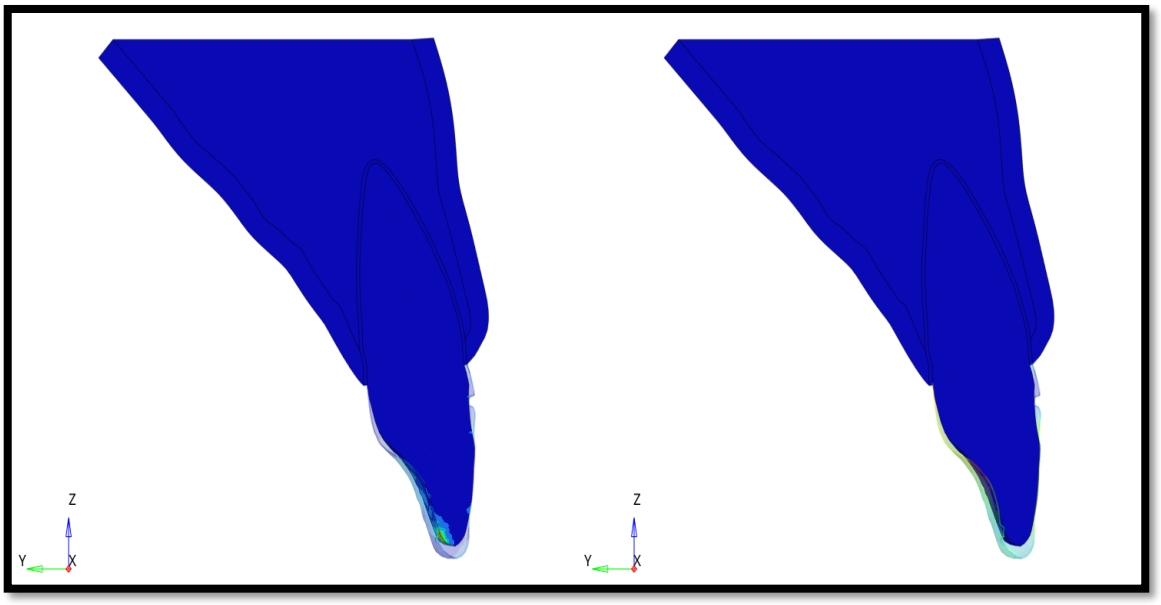


Figure 35- Displacement and Stress contours of the Thermoplastic Aligner in sectional view with rectangular power ridge attachment on both sides of maxillary incisors with 100 gm load.

“y”- axis

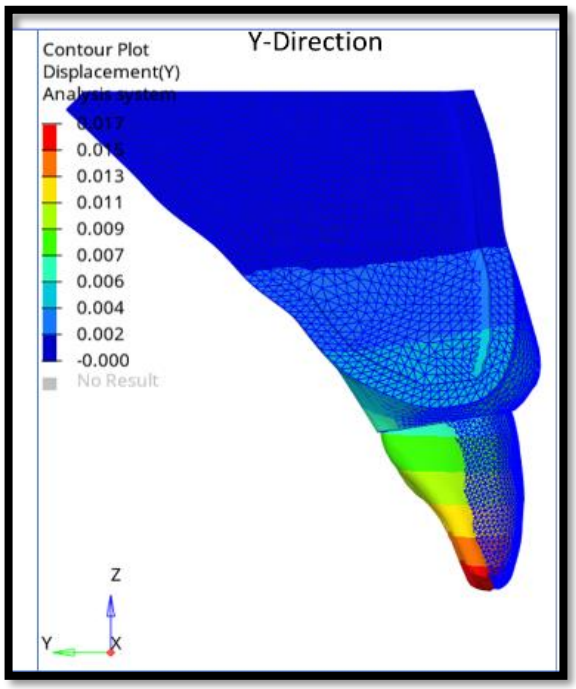


Figure 36- Displacement contour in Maxillary Central Incisor with only Thermoplastic Aligner with 50 gm load –no attachment.

‘y’- axis

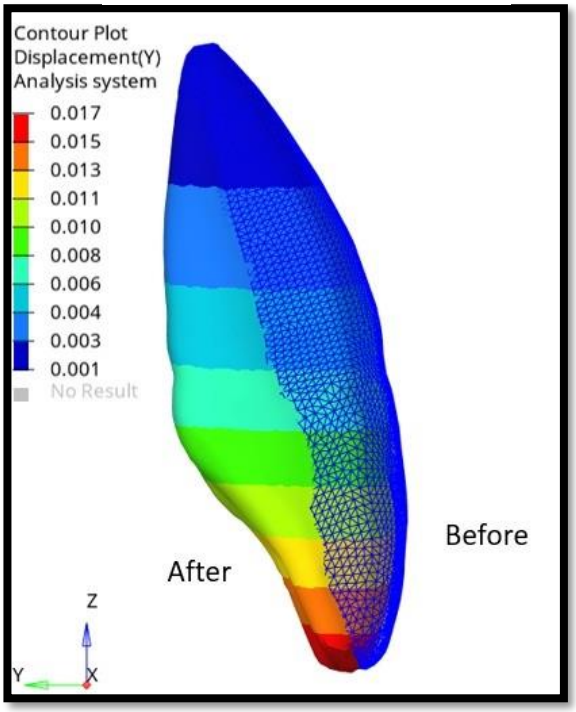


Figure 37- Displacement contour of maxillary central incisor with only Thermoplastic Aligner with 50 gm load –no attachment.

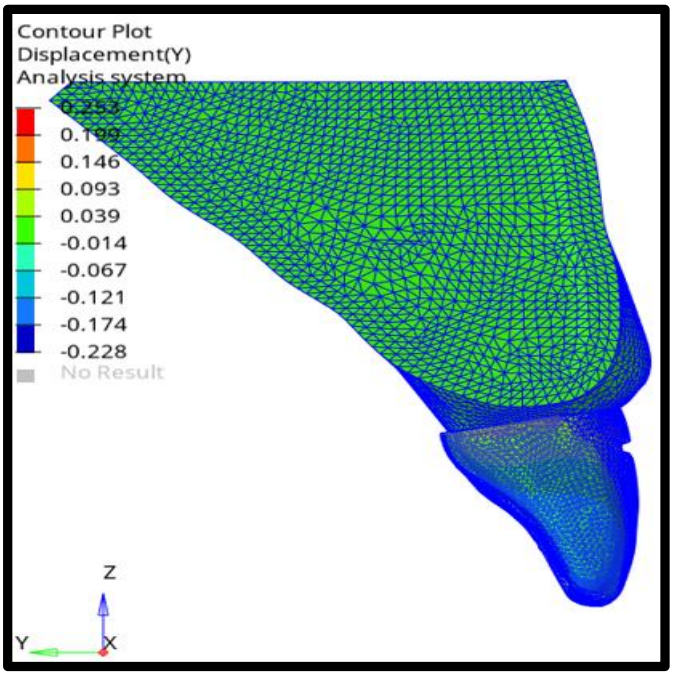


Figure 38- Displacement contour in Maxillary Central Incisor with thermoplastic Aligner with 50 gm load – Dual power ridge.

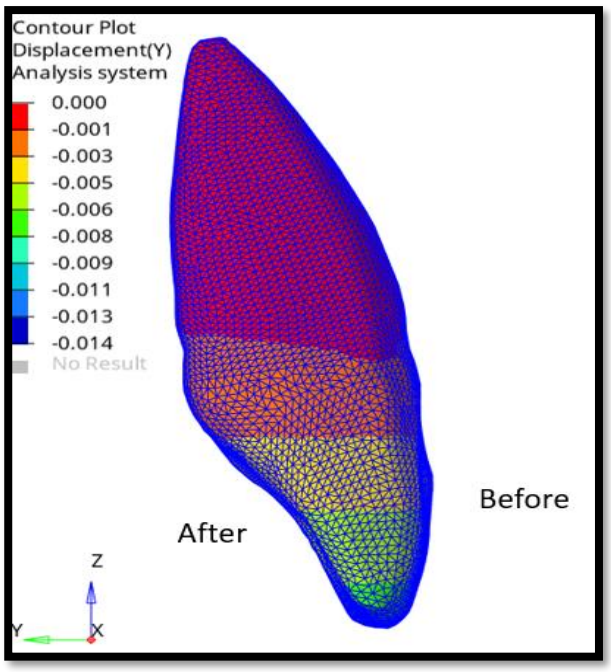


Figure 39- Displacement contour in Maxillary Central Incisor with thermoplastic Aligner with 50 gm load – Dual power ridge.

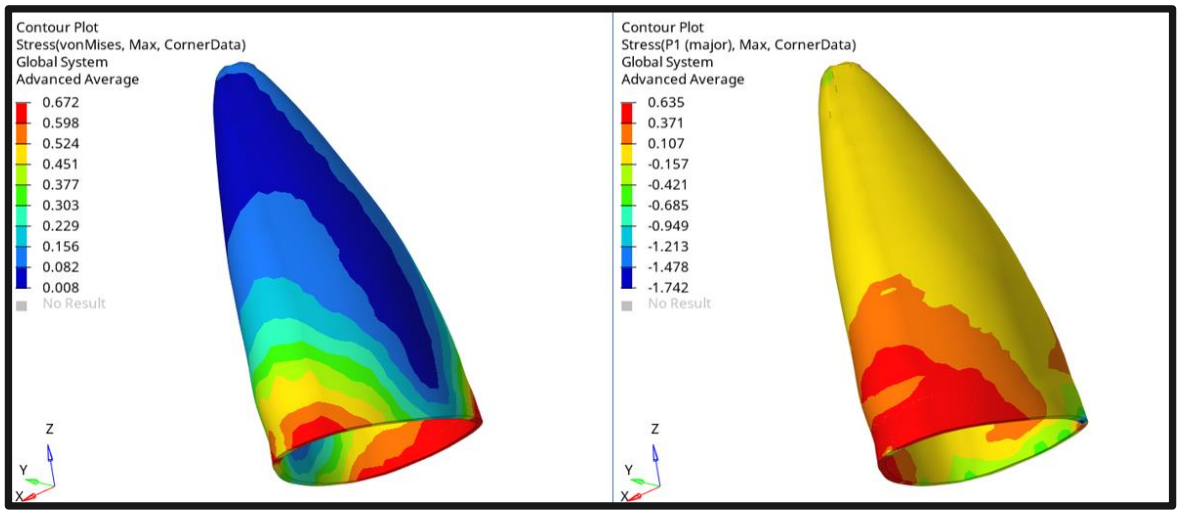


Figure 40- Stress contours of the Thermoplastic aligner at PDL on maxillary central incisors with 50 gm load in the tooth- Dual power ridge

Collectively, the FEM data confirm that dual-surface attachment designs enhance biomechanical efficiency by promoting bodily tooth movement and optimizing stress distribution, whereas power ridge attachments are prone to induce excessive crown tipping and localized overload. These findings reinforce the clinical imperative to customize attachment morphology and placement to the specific biomechanical requirements of torque delivery in clear aligner therapy. Despite these advancements, achieving consistent and physiologically compatible torque remains a challenge, warranting further research into attachment design, aligner stiffness, and force application protocols.

***

Discussion

DISCUSSION

In orthodontics, the concept of "torque" holds distinct interpretations in clinical versus biomechanical contexts. Clinically, as outlined by Andrews, torque describes the inclination of the crown in the anteroposterior direction for anterior teeth and in the transverse direction for posterior teeth. From a biomechanical perspective, torque is defined as the result of a force couple created by the torsional engagement of a rectangular archwire within a bracket slot, causing movement of the tooth root relative to the crown. Clinically, torque is evaluated by drawing a line along the Facial Axis of the Crown (FACC) and observing its angle to a perpendicular line through the incisal or occlusal edge. A "positive" torque indicates the root is tipped posteriorly while the crown tilts anteriorly; conversely, a "negative" torque implies the root moves forward with the crown inclined backward. This mechanical effect is simulated by the twisting of a rectangular wire inserted into the bracket slot. [25]

Effective torque control is critical for achieving ideal anterior guidance, which plays a role in correcting overjet and overbite, as well as for meeting aesthetic standards. Key variables influencing torque expression include tooth anatomy, bracket positioning, ligation method, and the type of archwire used. In clear aligner therapy, because the appliance fully encases the crown, determining the precise delivery of forces and moments becomes more complex. Finite element (FE) analysis has been widely utilized to study these mechanics, providing insights into scenarios like archwire activation, bodily labial movement of lateral incisors, sliding mechanics during canine retraction, and stress distribution within the periodontal ligament caused by conventional edgewise appliances.[1,25]

Aligner systems have evolved across generations.[40] The earliest systems relied solely on the aligner's material properties to deliver force, lacking any form of auxiliary aid. With advancements, second-generation systems introduced composite attachments to improve mechanical control of complex movements. In third-generation systems, such as those from Align Technology,[25,40] the force systems were further refined through the use of attachments like Power Ridges and ellipsoidal designs, with software algorithms dictating optimal placement for movement like torque, extrusion, and derotation..By regulating the force coupling and efficiently rotating the tooth around its center of resistance, Power Ridge, a "twist" in the aligner surface, keeps the aligner perfectly fitted at the gingival border. The "watermelon seed effect,[1,21]in which the gingival edge is distorted away from the tooth surface and forces are concentrated in the occlusal region, is prevented by the aligner material's twist, which does not alter its uniform thickness.[1,21] Previous investigations into the biomechanics of clear aligner therapy have indicated that specific attachment designs can significantly influence the efficacy of torque expression, particularly for achieving lingual root movement of the incisors.[34] Among these, horizontal ellipsoid attachments and rectangular composite attachments[25] have been identified as viable options. The study conducted by provided valuable insights into the performance of rectangular attachments. Their finite element analysis revealed that rectangular attachments tended to produce a greater degree of crown displacement relative to root movement.[34] This outcome suggests that the predominant mode of tooth movement achieved with clear aligners and these attachment designs is tipping rather than true bodily or torque-driven movement.[1,21,25,34]

Based on these findings, the present study incorporated rectangular labial attachments to assess their performance under controlled force applications. The rationale behind this

choice stems from the need to enhance torque expression by optimizing the point and direction of force application through geometrically stable attachment designs. When these results are compared to the observations made by it becomes evident that horizontal rectangular composite attachments may offer biomechanical advantages in achieving more controlled and effective crown movement, even if they fall short in inducing significant root displacement. This emphasizes the importance of attachment geometry in modulating the force system delivered by clear aligners and highlights the potential for further refinement in attachment design to enhance torque control outcomes in clinical settings.[24]

A retrospective study was conducted to evaluate Power Ridge's effectiveness in regulating the labio-lingual inclination of upper incisors.[21] They discovered that there was little variation between their virtual and real data, indicating that the power ridge is effective in expressing torque. With power ridges and ellipsoid attachments, Simon *et al.*[2] discovered that the initial mean moment and the amount of torque movement accomplished were 7.9 Nmm/6.7 Nmm and 51.5%/41.9%, respectively. This contrasts with the current investigation, which demonstrated that there was a 0.002 mm difference in the amount of root movement attained with ellipsoid attachment. In addition, there was a 0.029mm increase in overall displacement with the power ridge.[21] This could be explained by the movement of the crown tip caused by the power ridge. According to earlier studies, lingual root torque of incisors can be treated using rectangular composite attachments and horizontal ellipsoidattachments.[1,2,43]Based on the information provided, we employed the horizontal ellipsoid composite attachment designed by Align Technology to produce predictable tooth movements. When ellipsoid attachment occurs, the tooth's point of resistance receives both the force and the moment, which causes the lingual root to move and the tooth to move bodily. discovered that when rectangular

attachments were used, greater crown movement was attained than root movement, leading them to believe that aligners tilt teeth. In contrast to the findings described above.[21,25]

In this study, Finite Element Method (FEM) analysis was conducted to evaluate the biomechanical effects of different attachment designs under two force levels 50gm and 100 gm maxillary incisor torque control. The root displacement data revealed that the Power Ridge on both labial and palatal surfaces generated the highest root movement at 0.028 mm under 100gm load, while crown movement was negligible (0.000 mm), indicating efficient root torque without crown tipping. This was followed by the Power Ridge on the labial surface, which produced 0.003 mm of root displacement and 0.029 mm of crown movement at 100gm, suggesting combined root and crown movement, possibly due to asymmetric force application.

The horizontal ellipsoidal attachment also demonstrated effective root control, with 0.002 mm of root displacement and 0.023 mm crown displacement at 100gm. However, the semi-ellipsoidal attachment displayed reduced root movement (0.001 mm) and crown displacement (0.008 mm), indicating limited torque efficiency. The model without any attachment exhibited the least root movement (0.001 mm) and modest crown displacement (0.022 mm) at 100gm, confirming the limited torqueing capability of the aligner alone.

These findings contrast with previous reports, such as Simon *et al.*[2] where root torque efficiency with Power Ridges and ellipsoidal attachments was comparable. However, in this study, the dual Power Ridge model exhibited a significantly higher root displacement of 0.028 mm, compared to only 0.002 mm in the ellipsoidal model, indicating better

torque efficiency with the dual ridge configuration. This enhanced performance may stem from symmetric force application on both labial and palatal surfaces, directing the moment more precisely to the center of resistance of the tooth.

Stress analysis is critical in orthodontics to ensure that applied forces remain within biologically tolerable limits while achieving effective movement. In this FEM analysis, Von Mises stresses and displacement values were evaluated for each model under both 50gm and 100gm forces using 0.8 mm thick aligners.

At 100gm load, the highest crown displacement was recorded in the Power Ridge (labial) model at 0.029 mm, followed by the horizontal ellipsoidal attachment (0.023 mm), and the aligner-only model (0.022 mm). Interestingly, the Power Ridge (labial & palatal) model showed no crown displacement (0.000 mm), confirming effective force counterbalance. In contrast, the semi-ellipsoidal attachment produced the least crown displacement (0.008 mm), reflecting greater bodily control with minimal tipping. This mechanical behavior suggests that the semiellipsoidal attachment offers an optimal surface for force application, likely due to its broader contact area and favorable moment arm, which enhance rotational control of the crown while anchoring the root. The rounded geometry may also facilitate targeted plastic deformation of the aligner, promoting transmission of forces without unwanted tipping control.It outperformed the ellipsoidal design and rectangular power ridge, which exhibited moderate crown and root displacement. The semiellipsoidal shape’s anatomical conformity and mechanical interlock with the aligner likely promote more uniform stress distribution across the tooth surface during force application. However, when compared to labio-palatal power ridges, the tipping control was inferior, mainly due to the torquing effect of dual power ridges.

These findings align with previous finite element studies,[40-43] such as which underscore the significance of attachment geometry and contact surface design in modulating orthodontic force vectors.[43]Power ridge was more effective in controlling roots, while semi-ellipsoid attachment was more effective at labiolingual inclination. However, the power ridge may cause a distal twist of the maxillary incisors.[42] The semi-ellipsoidal attachment's ability to minimize bothcrown and rootdisplacement under varying loads highlights its potential utility in clinical scenarios.[1,7]

In terms of Von Mises stress on the teeth, the Power Ridge on the labial surface recorded the highest value at 6.64 MPa, indicating concentrated forces in the crown region. This was followed closely by the semi-ellipsoidal attachment (6.00 MPa) and horizontal ellipsoidal attachment (5.95 MPa). The aligneronly model demonstrated a moderate stress value of 5.65 MPa, while the dual Power Ridge configuration had the lowest stress value of 2.60 MPa, reinforcing the notion of distributed force with minimized crown stress.Periodontal ligament (PDL) stress followed a similar trend. The highest PDL stress at 100gm was observed with Power Ridge (labial) at 2.54 MPa, followed by aligner-only (2.22 MPa) and horizontal ellipsoidal (2.13 MPa). The dual ridge model again showed lower PDL stress (1.34 MPa), suggesting reduced load on periodontal structures despite effective root movement.

The semi-ellipsoidal attachment, while generating significant tooth stress, had notably low PDL stress at 100gm (0.579 MPa), which could be interpreted as limited stress transmission due to reduced movement. At 50gm force, stress and displacement values were proportionally lower across all models, confirming the load-dependent behavior of aligners.The patterns observed in this study align with the biomechanical principles governing torque expression: force magnitude, point of application, and the presence of

moments contribute to the direction and type of tooth movement. The dual Power Ridge design offers significant advantages by delivering a controlled moment with minimal crown displacement and maximal root effect, indicative of true torque. On the contrary, ellipsoidal attachments, while beneficial, showed relatively balanced root and crown movement, suggesting partial tipping alongside bodily motion.[42]

Stress concentration visualizations further demonstrated that high stress localized around anterior teeth gradually dissipated posteriorly, with minimal deformation observed in posterior aligner segments. This suggests that full-arch coverage contributes to better stress distribution and minimizes unwanted side effects like flaring or unintended movement.

Previous researchers, such as, have emphasized the importance of force couples in torque expression, which are often insufficient in attachment-free models. Our findings support this notion, as the aligner-only configuration consistently underperformed in both root movement and stress generation.[15] Moreover, as highlighted by the manufacturability of complex attachment designs like ellipsoids is limited beyond certain thickness thresholds (e.g., >1 mm), which could influence clinical application.[24]

The present study evaluated torque control efficiency using various attachment designs in clear aligner therapy, with a specific focus on dual power ridges under 50 gm and 100 gm loads. The findings revealed that periodontal ligament (PDL) stress with dual power ridges was 0.672 MPa at 50 gm and 1.34 MPa at 100 gm, whereas the stress at the root surface was 1.23 MPa at 50 gm and increased to 2.6 MPa at 100 gm. In terms of displacement, root movement was -0.014 mm at 50 gm and 0.028 mm at 100 gm, while crown displacement was negligible (0.00 mm). This indicates a predominantly root-

focused movement, suggesting effective torque delivery without unwanted crown tipping.

Literature shows,[1,22,43]that power ridge and ellipsoid attachments generated overall displacements of 0.98 mm and 0.75 mm, respectively, with corresponding stress values of 0.572 MPa and 0.0967 MPa.,however these values underscore the efficiency of power ridges over ellipsoidal designs in producing controlled movement, they also reflect a greater overall movement compared to our findings with dual power ridges. The lower displacement observed in our FEM model (0.011 mm overall for rectangular labial attachment and even less with dual power ridge) indicates enhanced control, likely due to improved force direction and confinement provided by the dual ridge configuration.

Interestingly, although prior studies emphasized that traditional power ridges are more effective in torque control than conventional attachments,[2] our study supports the notion that modifying ridge geometry to dual power ridges can further concentrate forces at the root apex while minimizing crown movement. This biomechanical advantage is further supported by the minimal crown displacement and increased root displacement, aligning with optimal torque expression.[16,29]

Moreover, the elevated stress values in the PDL observed with increasing force levels (from 0.672 MPa to 1.34 MPa) are within the threshold suggested in the literature for safe orthodontic loading without risking tissue necrosis or hyalinization**.** this implies that dual power ridges provide both efficient and biologically safe torque forces,[15] particularly under higher activation loads like 100 gm.

In conclusion, this FEM analysis reinforces the pivotal role of attachment design in controlling movement patterns and managing stress distributions in clear aligner therapy. Attachments that offer greater surface contact and multi-directional force application,

such as ellipsoidal and semicircular forms, demonstrate superior ability to mitigate unwanted tipping. However, they have limited scope for bringing about torquing movement. Power ridge on labial aspect has been a go to design in recent past for bringing about root movement, however our study shows that they are also not very efficient have a limited ability in bringing about the required root movement. Whereas,with power ridge on the cervical aspectof labial surface & incisal aspect of palatal surface, we were able to demonstrate a substantial amount of pure torque control & also mitigating amount of lingual/ palatal tipping of the crown.

***

Conclusion

CONCLUSION

This finite element study highlights the critical role of attachment design in torque control during clear aligner therapy. Dual power ridges on both labial and palatal surfaces delivered superior root movement, balanced force distribution, and reduced stress in periodontal tissues. Labial-only and ellipsoidal attachments showed limited torque efficiency and higher stress concentrations, while semicircular designs offered stability but insufficient root engagement. The results emphasize that precise attachment morphology and placement significantly influence biomechanical outcomes. Optimizing these parameters is essential for enhancing torque efficiency, minimizing undesirable movements, and improving overall treatment effectiveness in clear aligner-based orthodontics.

***

Summary

SUMMARY

This finite element analysis (FEA)based investigation systematically examined the biomechanical efficacy of various auxiliary attachment configurations in optimizing torque expression of the maxillary central incisor during clear aligner therapy. Five distinct models were simulated: an aligner without attachments, horizontal ellipsoidal, semi-ellipsoidal, rectangular power ridge on the labial surface, and dual rectangular power ridges on both labial and palatal surfaces. Under controlled orthodontic force magnitudes of 50gm and 100gm within the physiological threshold recommended for torque expression, the dual power ridge configuration consistently demonstrated superior biomechanical performance. Quantitative analysis revealed that this design produced the highest magnitude of root displacement (0.028 mm at 100gm) with negligible crown movement, signifying true root-centric torque and effective momenttoforce ratio optimization. Moreover, this configuration exhibited the lowest von Mises stress concentrations within the dental and periodontal structures, thereby minimizing the risk of undesirable tissue strain or iatrogenic effects. In contrast, models employing labial-only power ridges or ellipsoidal attachments demonstrated higher stress levels and disproportionate crown displacement, indicative of uncontrolled tipping and suboptimal force delivery. Thesemi-ellipsoidal attachment, although associated with minimal periodontal ligament (PDL) stress, exhibited poor torque efficiency due to insufficient root engagement. The study confirms that attachment geometry and spatial positioning profoundly influence the biomechanical environment, affecting both the directionality and magnitude of orthodontic forces. These findings underscore the necessity for precise attachment customization in aligner-based biomechanics to achieve efficient, predictable, and biologically safe

torque movements. By leveraging advanced computational modeling, this study contributes to the evidence-based refinement of clear aligner protocols, aligning with contemporary demands for esthetic, no invasive, and mechanobiological sound orthodontic interventions.

***

Bibliography

BIBLIOGRAPHY

1. V Sandhya, Arun A, Reddy VP, Mahendra S, Chandrashekar B, Aravind. Biomechanical Effects of Torquing on Upper Central Incisor with Thermoplastic Aligner: A ComparativeThree-Dimensional Finite Element Study with and Without Auxillaries. Journal of Indian Orthodontic Society.2021 Apr ;56(1):46-56.
2. Simon M, Keilig L, Schwarze J, Jung BA, Bourauel C. Treatment outcome and efficacy of an aligner technique--regarding incisor torque, premolar derotation and molar distalization. BMC Oral Health. 2014 Jun11; 14:68.
3. Rossini G, Parrini S, Castroflorio T, Deregibus A, Debernardi CL. Efficacy of clear aligners in controlling orthodontic tooth movement: a systematic review. Angle Orthod. 2015 Sep;85(5):881-9.
4. Karsli N, Ocak I, Gökcek S, Özsoy ÖP. Evaluation of the effect of attachments on torque control of palatally positioned maxillary lateral teeth with clear aligners: Finite element analysis. Korean J Orthod. 2025 Jan 25;55(1):58-68.
5. Jayade V, Annigeri S, Jayade C, &Thawani P. Biomechanics of Torque from Twisted Rectangular Archwires. Angle Orthod. 2007 Mar;77(2):214-20.
6. Vashishta A, Goyal V, Singh G, Kannan S, Singh RK, Chaudhari A. Unraveling the Role of Attachments in Clear Aligner Therapy. International Journal of Innovative Science and Research Technology 2023 July 8;7: 3112-15.
7. Costa R, Calheiros FC, Ballester RY, Gonçalves F. Effect of three different attachment designs in the extrusive forces generated by thermoplastic aligners in the maxillary central incisor. Dental Press Journal of Orthodontics. 2020 May;25(3):46–53.

8. McGuinness N, Wilson AN, Jones M, Middleton J, Robertson NR. Stresses induced by edgewise appliances in the periodontal ligament--a finite element study. Angle Orthod. 1992 Spring;62(1):15-22.

9. Knop L, Gandini Jr. LG, Shintcovsk RL, Gandini MR. Scientific use of the finite element method in Orthodontics. Dental Press J Orthod. 2015 MarApr;20(2):119-25.

10. Kojima Y, Fukui H. Effects of transpalatal arch on molar movement produced by mesial force: a finite element simulation. Am J Orthod Dentofacial Orthop. 2008;134(3): 335.e1–7.

11. Tominaga JY, Tanaka M, Koga Y, Gonzales C, Kobayashi M, Yoshida N. Optimal loading conditions for controlled movement of anterior teeth in sliding mechanics. Angle Orthod. 2009;79(6):1102-10.

12. Kanjanaouthai A, Mahatumarat K, Techalertpaisarn P, Versluis A. Effect of the inclination of a maxillary central incisor on periodontal stress. Finite element analysis Angle Orthod. 2012;82(5):812-9.

13. Ahmed T, Padmanabhan S, Pottipalli S H. Effects of Varying Attachment Positions on Palatal Displacement of Maxillary Incisors with Clear Aligner Therapy: A three-dimensional Finite Element Analysis. J OrofacOrthop. 2023 May;84(3):178-188.

14. Proffit WR, fields HW JR, Larsen BE, sarvar DM. Contemporary orthodontics. 6th edition. South East Asia: Elsevier. 2020.

15. Melsen B, Cattaneo PM, Dalstra M, Kraft DC. The Importance of Force Levels in Tooth Movement. Semin Orthod. 2007;13(4):220–33.

16. Kravitz ND, Kusnoto B, Agran B, Viana G. Influence of Attachments and Interproximal Reduction on the Accuracy of Canine Rotation with Invisalign. The Angle Orthodontist. 2008 Jul;78(4):682–7.

17. Liang W, Rong Q, Lin J, Xu B. Torque control of the maxillary incisors in lingual and labial orthodontics: a 3-dimensional finite element analysis. Am J Orthod Dentofacial Orthop. 2009;135(3):316-22.

18. Hahn W, Engelke B, Jung K, Dathe H, Fialka-Fricke J, Kubein-Meesenburg D, Sadat-Khonsari R. Initial forces and moments delivered by removable thermoplastic appliances during rotation of an upper central incisor. Angle Orthod. 2010 Mar;80(2):239-46.

19. Musilli M, Acanfora M, Gherlone E, Lucchese A. Anterior torque correction with bracketless fixed orthodontics. J Clin Orthod. 2012 Sep;46(9):558-62.

20. Krieger E, Seiferth J, Marinello I, Jung BA, Wriedt S, Jacobs C, Wehrbein H. Invisalign® treatment in the anterior region: were the predicted tooth movements achieved? J OrofacOrthop. 2012 Sep;73(5):365-76.

21. Castroflorio T, Garino F, Lazzaro A, Debernardi C. Upper-incisor root control with Invisalign appliances. J Clin Orthod. 2013 Jun;47(6):346-51.

22. Dasy H, Dasy A, Asatrian G, Rózsa N, Lee HF, Kwak JH. Effects of variable attachment shapes and aligner material on aligner retention. Angle Orthod. 2015;85(6):934-40.

23. Rossini, G, Parrini S, Castroflorio, Deregibus A, Debernardi CL.Periodontal health during clear aligners treatment: a systematic review. Eur J Orthod. 2015 Oct;37(5):539-43.

24. Cai Y, He B, Yang X, Yao J. Optimization of configuration of attachment in tooth translation with transparent tooth correction by appropriate moment-to-force ratios: Biomechanical analysis. Biomed Mater Eng. 2015;26 Suppl1: S507-17.

25. Lacarbonara M, Accivile E, Abed MR, Teresa DM, Monaco A, Marzo G, CapogrecoVariable torque prescription: state of art. Open Dent J. 2015 Jan 30;9:60-4.

26. Gomez JP, Peña FM, Martínez V, Giraldo DC, Cardona CI. Initial force systems during bodily tooth movement with plastic aligners and composite attachments: A three-dimensional finite element analysis. Angle Orthod. 2015 May;85(3):454-60.

27. Garino F, Castroflorio T, Daher S, Ravera S, Rossini G, Cugliari G, Deregibus A. Effectiveness of Composite Attachments in Controlling Upper-Molar Movement with Aligners. J Clin Orthod. 2016 Jun;50(6):341-7.

28. Gao L, Wichelhaus A. Forces and moments delivered by the PET-G aligner to a maxillary central incisor for palatal tipping and intrusion. Angle Orthod. 2017 Jul;87(4):534-541.

29. Weir T. Clear aligners in orthodontic treatment. Aust Dent J. 2017 Mar;62 Suppl 1:58-62.

30. Yokoi Y, Arai A, Kawamura J, Uozumi T, Usui Y, Okafuji N. Effects of Attachment of Plastic Aligner in Closing of Diastema of Maxillary Dentition by Finite Element Method. J Healthc Eng. 2019 Mar 3; 2019:1075097.

31. Gupta M, Madhok K, Kulshrestha R, Chain S, Kaur H, Yadav A. Determination of stress distribution on periodontal ligament and alveolar bone by various tooth movements.A 3D FEM study. Oral Biol Craniofac Res. 2020;10(4):758–63.

32. Cattaneo PM, Cornelis MA. Orthodontic Tooth Movement Studied by Finite Element Analysis: An Update. What Can We Learn from These Simulations? Curr Osteoporos Rep. 2021;19(2):175-181.

33. Gaddam R, Freer E, Kerr B, Weir T. Reliability of torque expression by the Invisalign® appliance: A retrospective study. Australasian Orthodontic Journal. 2021;37(1):3–13.

34. Nucera R, Dolci C, Bellocchio AM, Costa S, Barbera S, Rustico L, Farronato M, Militi A, Portelli M. Effects of Composite Attachments on Orthodontic Clear Aligners Therapy: A Systematic Review. Materials (Basel). 2022 Jan 11;15(2):533.

35. Cheng Y, Gao J, Fang S, Wang W, Ma Y, Jin Z. Torque movement of the upper anterior teeth using a clear aligner in cases of extraction: a finite element study. Progress in orthodontics. 2022 Aug 1;23(1).

36. Bichu YM, Alwafi A, Liu X. Andrews J, Ludwig B., Bichu A Y,.Advances in orthodontic clear aligner materials. Bioact Mater. 2022 Oct 20; 22:384-403.

37. Jedliński M, Mazur M, Greco M, Belfus, J, Grocholewicz K, Janiszewska-Olszowska J. Attachments for the Orthodontic Aligner Treatment State of the Art, A Comprehensive Systematic Review. Int J Environ Res Public Health. 2023 Mar 2;20(5):4481.

38. Liu X, Wu J, Cheng Y, Gao J, Wen Y, Zhang Y, *et al.* Effective contribution ratio of the molar during sequential distalization using clear aligners and micro-implant anchorage: a finite element study. Prog Orthod. 2023 Oct 9;24(1):35.

39. Castroflorio T, Sedran A, Parrini S, Garino F, Reverdito M, Capuozzo R, Mutinelli S, Grybauskas S, Vaitiekūnas M, Deregibus A. Predictability of

orthodontic tooth movement with aligners: effect of treatment design. Prog Orthod. 2023 Jan 16;24(1):2.

40. Alhasyimi AA, Ayub A, Farmasyanti CA. Effectiveness of the Attachment Design and Thickness of Clear Aligners during Orthodontic Anterior Retraction: Finite Element Analysis. Eur J Dent. 2024 Feb;18(1):174-181.

41. Gandhi A, Singh D, Fatima K., Tripathi T, & Rai P. Finite element analysis-A biomechanical tool in orthodontics. IP Indian Journal of Orthodontics and Dentofacial Research, 2024;10(1):11–15.

42. Hong YY, Kang T, Chen X. Effect of varying auxiliaries on maxillary incisor torque control with clear aligners: A finite element analysis. Am J Orthod Dentofacial Orthop. 2024 Jul;166(1):50-60.

43. Pede K, Shetty P, Ranjan A, Khan W, Patil H, Mishra H. Evaluation of effects of different sizes and shapes of attachments during rotation, tipping, and torquing in clear aligner therapy – A finite element study. J Orthod Sci. 2024;13(1):30.

44. Al-Samman M, Sadek M, Hamdan AM. Comparison of the predicted and achieved labiolingual inclinations of the maxillary central incisors in adult Class II division 2 malocclusions treated with clear aligners. Korean J Orthod. 2024 Nov 25;54(6):403-410.

45. Liu Y, Guo L, Feng Y, Hua J, Dai Q, Chen Z, Song W, Guo B, Chen T, Ji L. Comparative study of torque expression and its biomechanical effects: spherical self-ligating bracket with lock-hook system versus passive self-ligating bracket and conventional bracket. BMC Oral Health. 2025 Jan 6;25(1):30.

***

Annexures

ANNEXURE – I
ETHICAL CLEARANCE CERTIFICATE

SANTOSH
Deemed to be University
(Established u/s 3 of the UGC Act, 1956)

F. No. SU/2023/2480[18] Dated: 26.09.2023

Subject: Grant of Ethical Clearance for Thesis Protocol Topic "Effect of attachment type on torquing of maxillary incisors in aligner orthodontics a finite element study", submitted by **Dr. NALIN YADAV,** MDS student of Batch 2022-2023, Department of **ORTHODONTICS & DENTOFACIAL ORTHOPAEDICS**.

*****

With reference to his/her request for grant of Ethical Clearance for the Thesis Protocol entitled "Effect of attachment type on torquing of maxillary incisors in aligner orthodontics a finite element study"; **Dr. NALIN YADAV** is informed that the Thesis Protocol submitted by him/her was considered by the **Screening Committee** of the Santosh Dental College & Hospital in its meetings held on 07.02.2023 & 08.02.2023. The recommendations of the **Screening Committee** were considered in detail by the Institutional **Ethics Committee** in its meeting held on **23.09.2023** and the same was **approved** by the **Ethics Committee**.

He /She is informed accordingly for further necessary action.

[DR. NARESH SHARMA]
REGISTRAR

SANTOSH "DEEMED TO BE UNIVERSITY" REGISTRAR GHAZIABAD, NCR (DELHI)

Dr. NALIN YADAV
MDS student of batch 2022-2023
Department of ORTHODONTICS & DENTOFACIAL ORTHOPAEDICS
Email: dr.nalinyadav23@gmail.com

Copy to:
1. The Vice Chancellor
2. The Dean, SDC&H
3. The Dean – Research
4. The Dean – Academics
5. The Director - IQAC
6. **Dr. Nishant Gupta** (Guide)
7. HOD of **ORTHODONTICS & DENTOFACIAL ORTHOPAEDICS**

ANNEXURE – II
LAB CERTIFICATE

RUTHVI TECH SOLUTIONS PVT LTD.

CERTIFICATE

This is to certify that the dissertation entitled **"EFFECT OF ATTACHMENT TYPE ON TORQUING OF MAXILLARY INCISORS IN ALIGNER ORTHODONTICS: A FINITE ELEMENT STUDY"** is a bonafide work meticulously planned and carried out by **"DR. NALIN YADAV"** a post graduate student of Department of Orthodontics and dentofacial orthopedics, "Santosh Dental College & Hospital, Santosh deemed to be University of Ghaziabad, Delhi-NCR. Under the technical guidance of **"Mr.Rupeshkumar"** (Technical Manager).

The observation and results recorded by him are genuine to the best of my knowledge.

Technical manager,
Ruthvi Tech Solutions Pvt,LTD

No.51, 3rd floor, 1st Main, Vidyavinayaka Nagar, Bengaluru: 560103

ANNEXURE III

ANTI-PLAGIARISMCHECKREPORT

Nalin Yadav

Dr. Nalin Yadav Thesis.docx

Santosh University, Ghaziabad

Document Details

Submission ID
trn:oid:::3618:99614301

Submission Date
Jun 6, 2025, 10:41 AM GMT+5:30

Download Date
Jun 6, 2025, 10:43 AM GMT+5:30

File Name
Dr. Nalin Yadav Thesis.docx

File Size
10.9 MB

71 Pages

6,727 Words

40,887 Characters

5% Overall Similarity

The combined total of all matches, including overlapping sources, for each database.

Filtered from the Report

- Bibliography

Match Groups

35 Not Cited or Quoted 5%
Matches with neither in-text citation nor quotation marks

0 Missing Quotations 0%
Matches that are still very similar to source material

0 Missing Citation 0%
Matches that have quotation marks, but no in-text citation

0 Cited and Quoted 0%
Matches with in-text citation present, but no quotation marks

Top Sources

1% Internet sources

5% Publications

0% Submitted works (Student Papers)

***